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MEASUREMENT OF TRANSIENT BORE-SURFACE TEMPERATURES IN 7.62 MM GUN TUBES

C. E. Moeller, et al

Midwest Research Institute

Prepar d tor:

Rock Island Arsenal

November 1973

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As a segment of a gun tube erosion analysis program, techniques were studied to measure transient bore-surface temperatures in 7.62MM M60 machine gun barrels. Rapid-response surface thermocouples (Chromel/Alumel and iron/nickel) were utilized with high-speed recorders and play-back systems to follow the rise and decay characteristics of the pulsed heating phenomenon during firing. In addition to electronics circuitry problems, two factors were found to obscure the measurements: recession of the thermocouple tip during firing and coating of the thermocouple junction by debris. However, when these factors were minimized,

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20. peak surface temperatures near the rifling origin exceeded 1400°F during the initial rounds of a burst and surpassed 1500°F after 100 rounds of continuous fire. (U) (Moeller, C. E. and Bossert, A. J.)

FOREWORD

This report was prepared by Messrs. C. E. Moeller and A. J. Bossert of the Midwest Research Institute under Contract DAAF03-70-C-0045.

The contract was part of a continuing gun barrel technology program authorized and funded by the U. S. Small Arms Systems Agency.

The Project Engineer for this study was Dr. W. T. Ebihara of the Research Directorate, GEN Thomas J. Rodman Laboratory, Rock Island Arsenal.

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INTRODUCTION

Many of the difficulties encountered in attempting to quantitatively describe gun tube erosion lie in the lack of data concerning temperature and stress distribution measurements under transient loading conditions. Temperature measurements of the bore surface area are necessary for the evaluation of erosion, thermal stresses and heat transfer. Thermocouples used in the past were limited because the response times were long compared with the firing pulse duration.

The current project was undertaken to test contemporary surface thermocouples with response-time capabilities of the order of 10^{-6} second to supplement a small arms erosion analysis program. Midwest Research Institute (MRI) conducted the measurements at their Deramus Field Station.

The special bore surface thermocouples were purchased from Heat Technology Laboratory and Medtherm, Inc., and were of the type developed and tested by MRI for the U. S. Army under Contract DA-23-072-ORD-12 and DA-23-072-ORD-13 in the early 1950's.

TEST PROGRAM

The test program consisted of the measuring of bore surface temperatures at six stations and of external surface temperatures at two stations during a burst of 125 rounds. The temperatures were obtained for a standard lined barrel, and for an unlined, unplated barrel. The lined barrel was also exposed to six additional bursts of 125 rounds with less than a minute between bursts for temperature measurements. Ammunition used in the tests was 7.62MM-NATO, Ball M80, WC846 Propellant, linked for the M60 machine gun.

TEST EQUIPMENT

The test firings were conducted at the MRI Range Facility. The machine gun was mounted on a steel pedestal which was bolted to the concrete floor of the

firing bay as shown in Figure 1. An improvised trough for holding a belt of 125 rounds was clamped adjacent to the gun on the pedestal. The test equipment used in the firings consisted of the instrumented gun and the recording instruments.

A. Instrumented Gun

The particular gun used in the tests was an M60C Machine Gun with a standard M60 (Stellite-lined) gun barrel and an unplated, unlined Cr-Mo-V steel gun tube. Special bore surface thermocouples were mounted in the barrels at six stations, external surface thermocouples at two stations. A view of the gun with the unlined barrel is given in Figure 2; a closeup view of the installed thermocouples is shown in Figure 3. All bore surface thermocouples were located so that their sensitive surfaces were aligned with the surfaces of the grooves in the barrel. The positions of the thermocouples are given in Table I and are the same for both barrels. However, a different set of thermocouples was used for each barrel.

TABLE I

LOCATIONS OF THERMOCOUPLES

Station Number	Distance From Origin of Rifling	Angular Displacement from Top*
Bore Surface Thermocouples		
1	1.0 in.	-90°
2	1.0 in.	0
3	1.0 in.	$+90^{\circ}$
4	1.5 in.	$+30^{\circ}$
5	5.5 in.	$+60^{\circ}$
6	6.0 in.	-30°
External Thermocouples		
4X	1.5	$+30^{\circ}$
6X	6.0	-30°

* (+) clockwise when viewed from rear of barrel.

FIGURE 1. Mounted M60 Machine Gun in Firing Bay

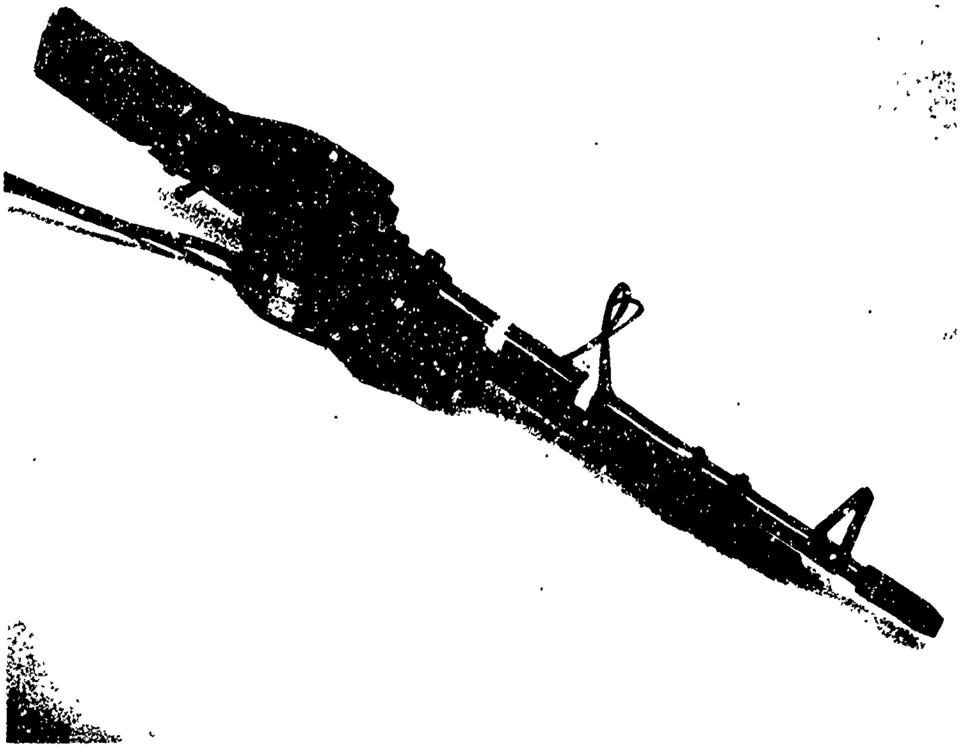


FIGURE 2. M60 Machine Gun with Instrumented Barrel

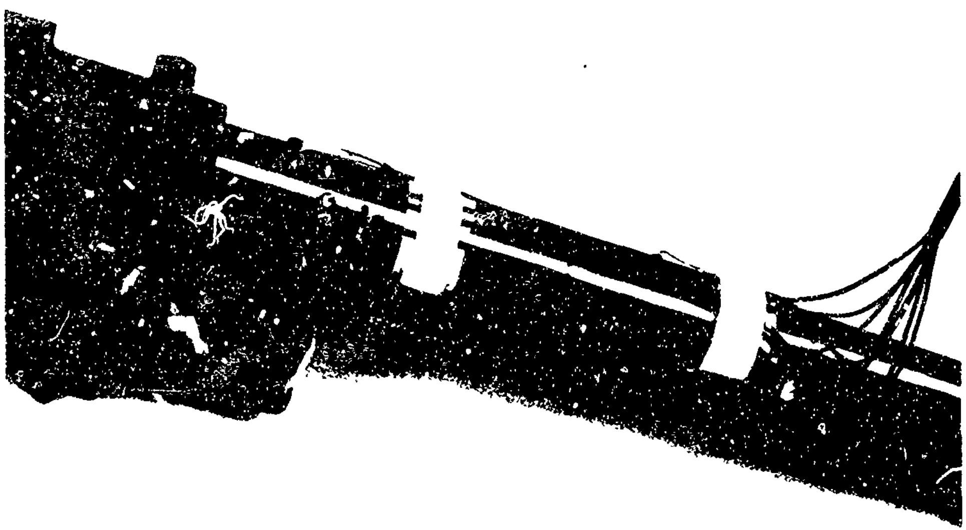


FIGURE 3. Closeup View of Instrumented Barrel Indicating Techniques of Thermocouple Installation

1. Bore surface thermocouple: Design and mounting details of the bore surface thermocouple are shown in Figures 4 and 5. The flat end of the probe is the temperature sensing-surface and is sufficiently small to blend into the cylindrical surface of the 0.308 in. I.D. bore. Hence, the probe does not appreciably disturb the localized gas flow through the barrel during the firing of a round.

Chromel*/Alumel* and iron/nickel thermocouples were fabricated by Heat Technology Laboratory and Medtherm, Inc., from materials selected on the basis of their thermal diffusivities which more closely matched those of the lined gun barrel than any other available thermocouple materials. Chromium plating was used on the sensing surfaces of the thermocouple because it more closely duplicated the surface properties of the lined barrel than any other available plating material.

Fiber glass insulated thermocouple cables were used between the bore surface thermocouples and the instrument room. The wires were connected to the thermocouples in a manner which minimized vibrational forces on the thermocouples during firing. The Chromel wires were clamped between locking nuts on the threaded Chromel bodies of the thermocouples and the Alumel wires spot-welded to the Alumel wires of the thermocouples.

The thermocouples were sealed in the threaded holes at the six stations by copper gaskets at two locations: (1) the bottom of the threaded body of the thermocouple, and (2) the bottom of the locking nut on the threaded body.

2. External surface thermocouples: The external surface thermocouples were fabricated by twisting and welding together the wires from glass fiber-insulated Chromel/Alumel cables. The twisted thermal junctions were clamped against the barrel by the bottom lock nuts of the bore surface thermocouples at the two stations; this installation is shown in Figure 3. The Chromel/Alumel wires from all thermocouples were soldered into a connector for easy removal from the wires to the recording instruments.

* Trade names of Hoskins Manufacturing Company.

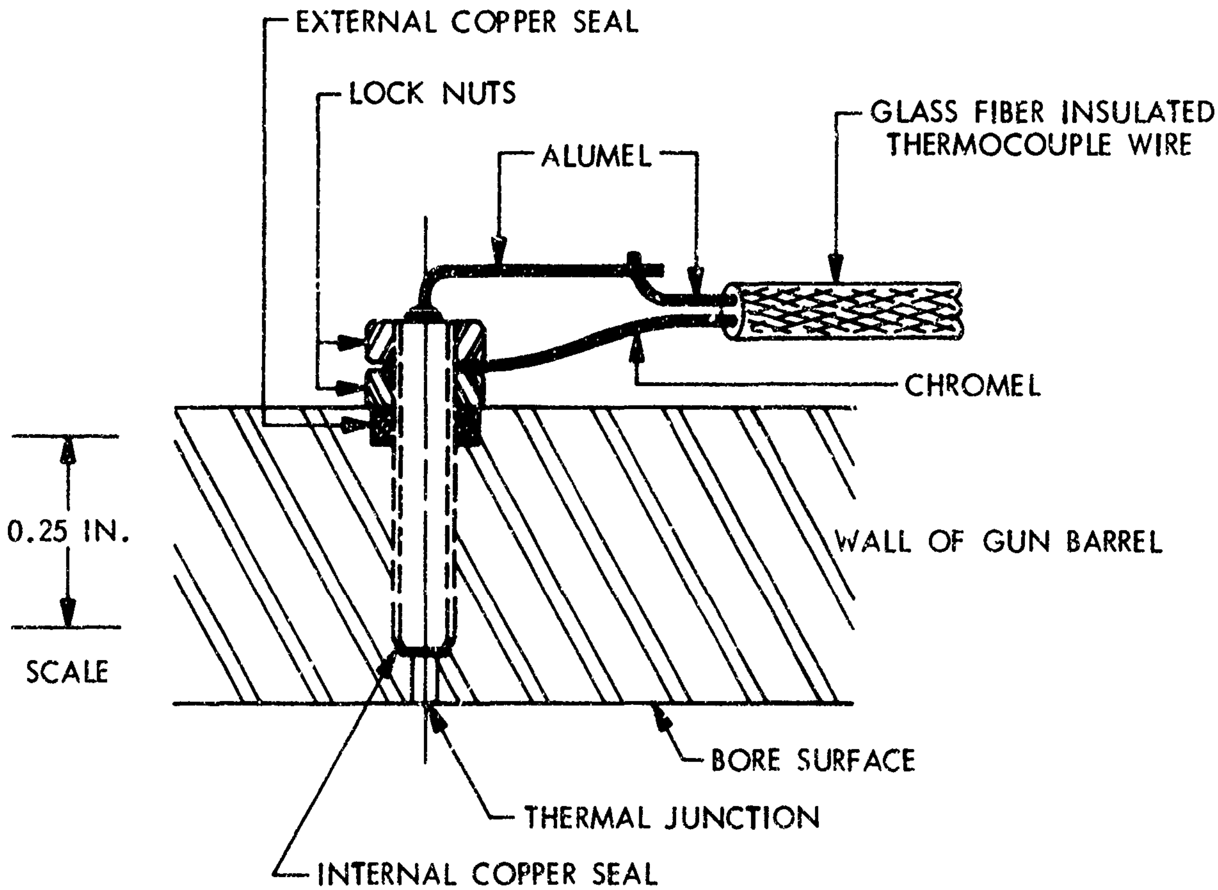


FIGURE 4. Details of Uninsulated Bore Surface Thermocouple

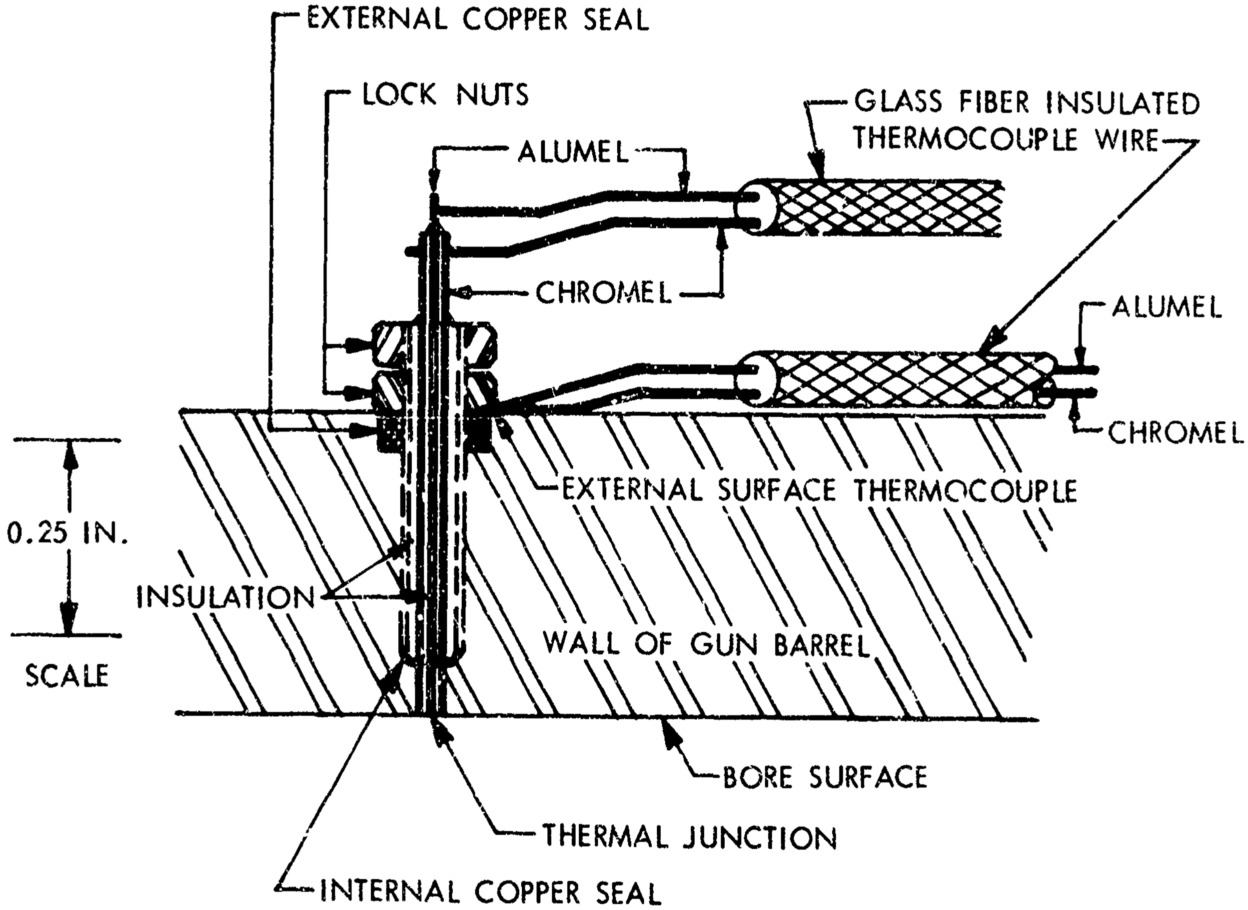


FIGURE 5. Details of Insulated Bore Surface Thermocouple

B. Recording Instruments

The instruments for recording the thermocouple signals were located in the firing control room adjacent to the firing bay. The thermocouple wires from the mating connector extended into the control room and ended at an ice reference-bath where they were connected to copper wires. Two pairs of copper wires from the external surface thermocouples were connected to a Texas Instrument Oscilla/Riter, one pair from Station 4 bore surface thermocouple was connected to an Ampex DAS-100 data acquisition system, and five pairs from the remaining bore surface thermocouples were connected to a Honeywell Visicorder. These recording instruments are shown in Figure 6. The Ampex system had only one D.C. amplifier and, hence, could be used for the one thermocouple (Station 4). The A.C. amplifiers in the system were used to record the rapidly changing thermocouple signals during the firing of a round, but their low frequency cutoff (0.1 cps) caused loss of the D.C. portion of the thermocouple signal between individual rounds; hence, the slowly changing temperatures could not be obtained with them. The signals from the bore surface thermocouples at Stations 1 and 6 were recorded on both the Visicorder and the Ampex (A.C. channels). Ground wires were required between the gun and each of the recorders to reduce the signal noise to a tolerable level.

For the final series of measurements, only the Honeywell 1508 Visicorder with Accudata 104 DC amplifiers was used to record all bore surface temperatures. Attempts to make simultaneous recordings of the bore surface and the external surface temperatures with the same instrument resulted in increased noise pickup and a significant shift in both thermocouple readings. For this reason, all external surface temperatures were measured with a West Model 9B potentiometer. The same potentiometer was used to calibrate the Visicorder before each series of tests and to calibrate the bore surface thermocouples in the laboratory.

Calibration procedure for the Visicorder was as follows: First the zero signal position of the recorder trace was adjusted to correspond with the ambient temperature in the firing bay, then the potentiometer was set to deliver the millivolt equivalent of 1600°F to the amplifier input through the extension cable, and finally the amplifier gain was adjusted until the recorder trace indicated 1600°F. Calibration traces were then recorded for 2000°, 1600°, 1200°, 800°, 400°, and ambient temperature.

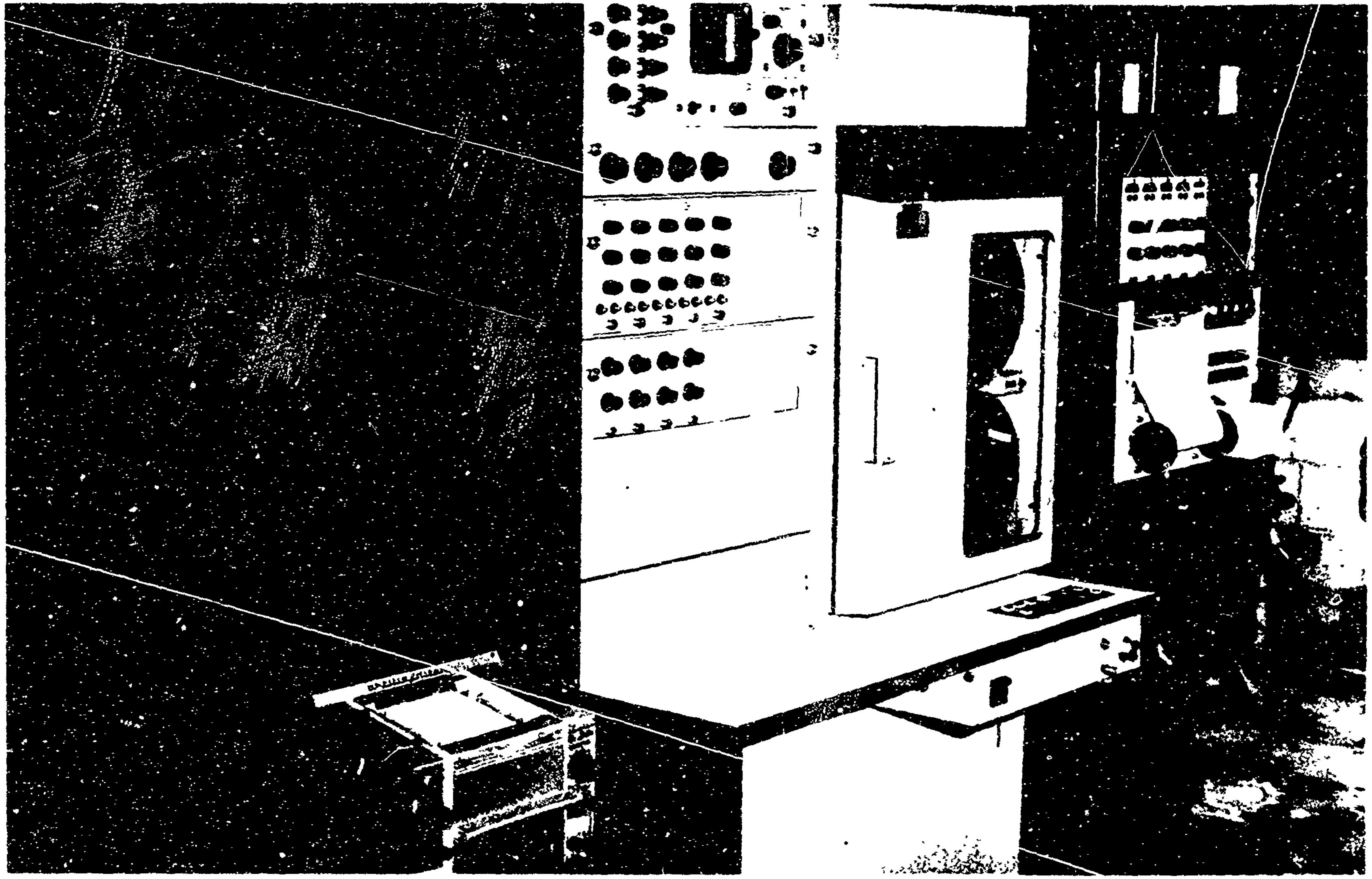


FIGURE 6. Recording Equipment, Texas Instruments Oscilla/Riter, Ampex DAS-100 System, and Honeywell Visicorder (Left to Right)

Calibration procedure for the bore surface thermocouples consisted in the heating of a 1-lb. aluminum block until the surface temperature of the block stabilized at a chosen temperature. The probe of the bore surface thermocouple was placed in firm contact with the aluminum block. The output of the bore surface thermocouple was compared to the output of a standard thermocouple attached to an adjacent position on the aluminum block. The bore surface thermocouples were within 9° of the standard at 500°F and within 5° at 1100°F.

TEST PROCEDURE

The instrumented machine gun was installed on the pedestal in the firing bay at the beginning of each day of firing; it was secured in a locked building at all other times. After the ice bath for the thermocouple reference junctions had been serviced, the calibration of all recording channels was checked with the potentiometer. The calibrations and recording speeds for the respective recorders were set as follows: (1) Oscilla/Riter, 5 mv/cm and 2mm/sec; (2) Ampex DAS-100, 5 mv/in and 60 in/sec; and (3) Visicorder, 10 mv/in and 40 in/sec. The Ampex DAS-100 is a magnetic-tape recording system; the signals recorded on the tape were transcribed onto the Visicorder chart paper (for a visual record) at a playback speed of 1-7/8 in/sec. Hence, the equivalent recording speed for the Ampex-Visicorder combination was 1,280 in/sec or 0.78 msec/in of chart paper.

The bore surface thermocouples were installed in the barrel and were adjusted flush with the bore. The external surface thermocouple was installed and then the thermocouples were checked for continuity. The instrumented barrel was then installed in the receiver and the thermocouples were connected to the extension cables. The range warning lights were turned on, ammunition was loaded into the gun, and the gate of the firing bay was secured. The recorder was then started and, after approximately 1 second, the firing switbhes were closed to start the burst.

After each burst, the gun was inspected to ensure that no live rounds were in the gun. After this inspection, range warning lights were turned off. At this point the Visicorder record was examined to ensure a satisfactory recording. After most of the bursts, the bore surface thermocouple was examined with a borescope and the condition of the thermocouple was noted. The position of the bore surface thermocouple was adjusted if necessary or another thermocouple was installed and prepared for the next burst.

RESULTS AND DISCUSSION

Results of the surface temperature measurements are presented for the lined and the unlined barrels during single 125-round bursts and during six additional 125-round bursts for the lined barrel. These results and the anomalies which occurred are discussed.

The bore surface temperatures were determined from the Visicorder records. The signals recorded on the Ampex DAS-100 data acquisition system were played back into the Visicorder at 32 times real-time to achieve an expanded time scale. Records from the first round for Stations 1 and 6 with this expanded time scale are given in Figure 7; the indicated initial and peak temperatures are listed.

The initial and peak bore surface temperatures for the 125-round burst for the unlined barrel are presented for the six stations in Figures 8 through 14; these data are also given in Table I of Appendix B. Maximum indicated peak temperature was 1260°F, maximum initial value, 470°F.

The indicated initial and peak bore surface temperatures for the first 125-round burst for the lined barrel are presented for five stations (Station 4 was not usable in the lined barrel) in Figures 14 through 18; these data are given in Table II of Appendix B. The indicated initial and peak surface temperatures of the 1st, 25th, 50th, 75th, 100th, and last round of Bursts 1 through 7 are plotted in Figures 19 through 23, and given in Table III of Appendix B. Maximum indicated peak temperature was 1380°F, which occurred during the fourth burst; 700°F was the maximum initial value prior to firing of a round and this occurred at the end of the sixth burst. The gun jammed during the

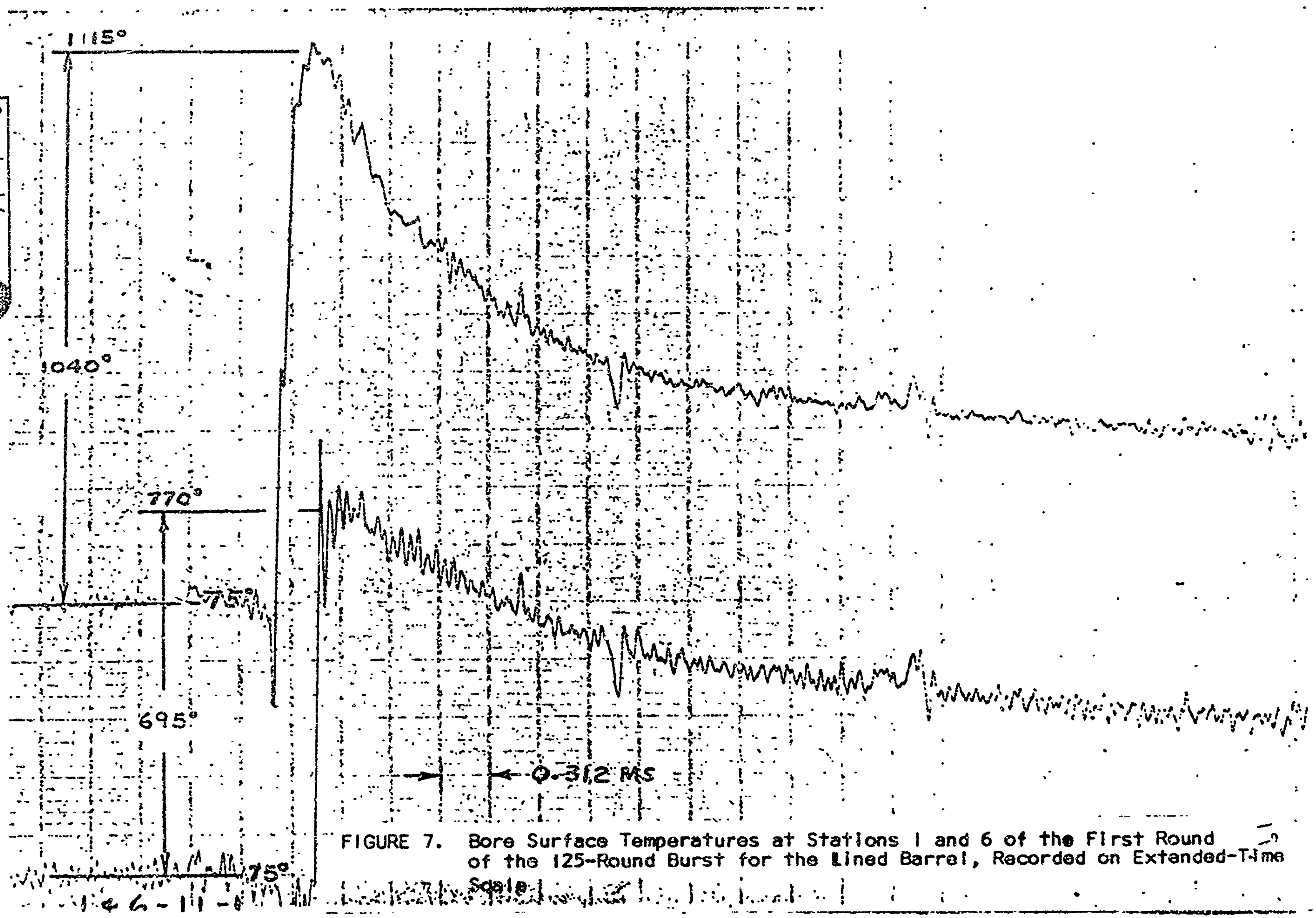


FIGURE 7. Bore Surface Temperatures at Stations 1 and 6 of the First Round of the 125-Round Burst for the Lined Barrel, Recorded on Extended-Time Scale

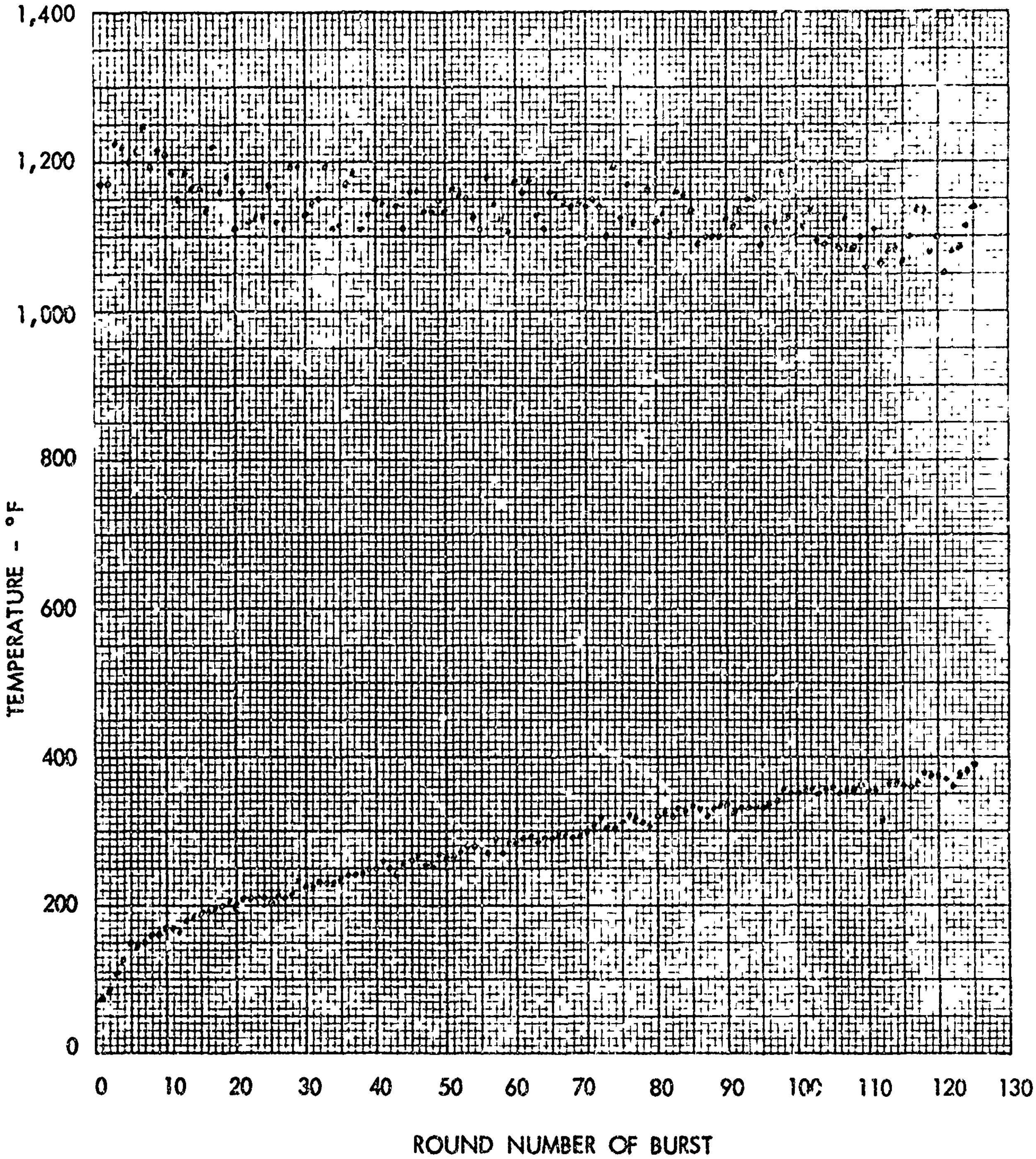


FIGURE 8. Station 1, Initial and Peak Bore Surface Temperatures for 125 Rounds, Unlined Barrel

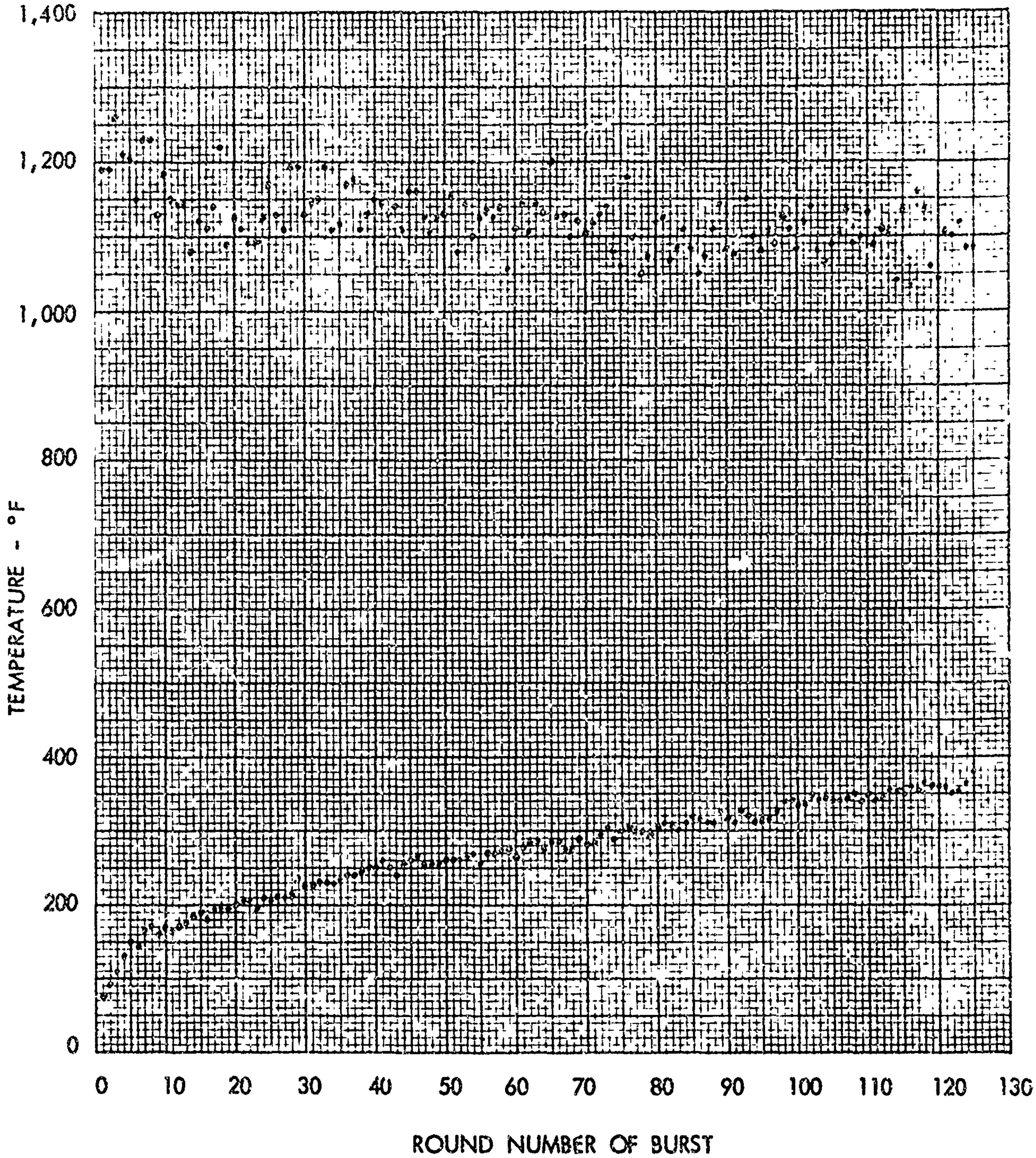


FIGURE 9. Station 2, Initial and Peak Bore Surface Temperatures for 125 Rounds, Unlined Barrel

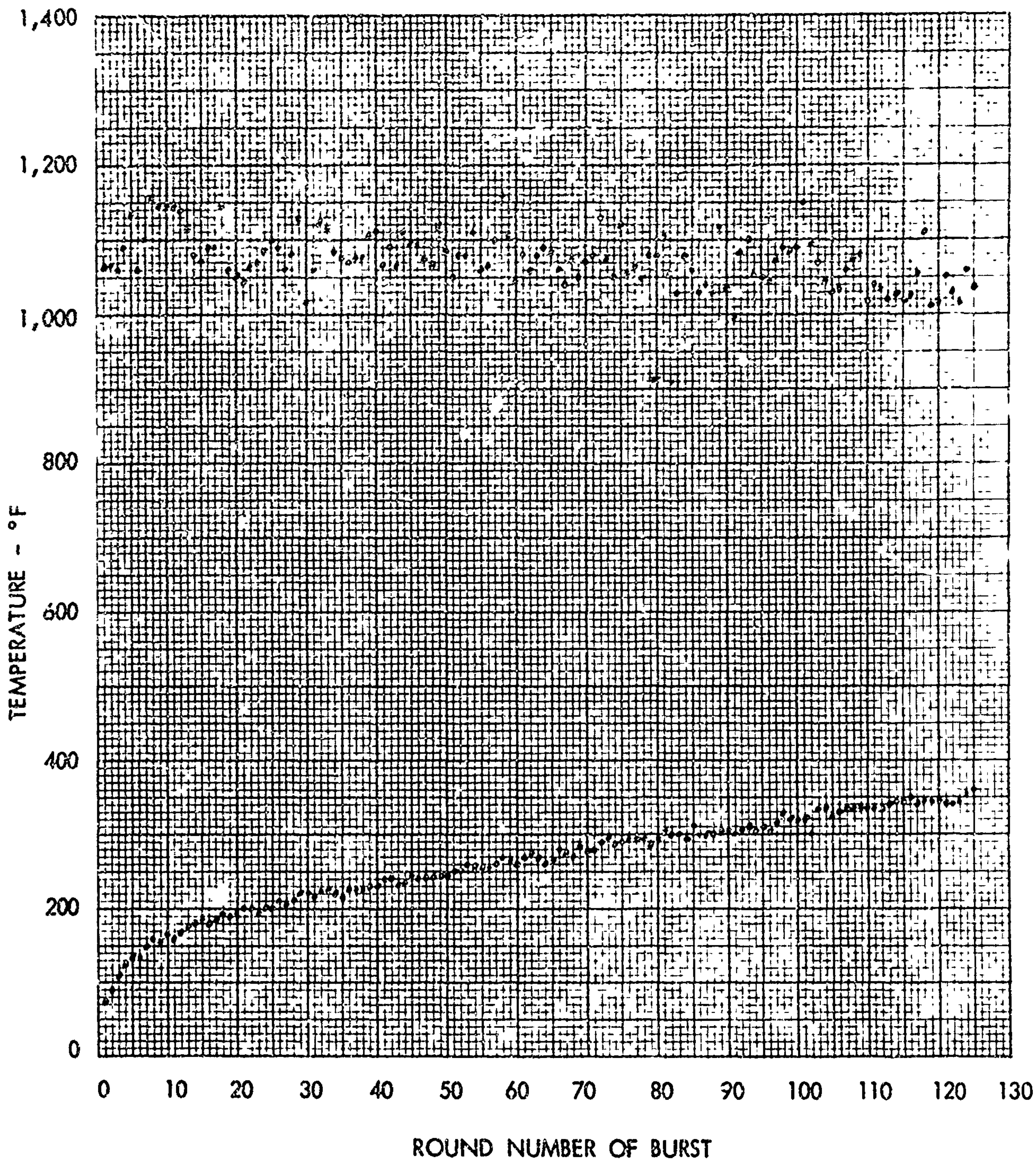


FIGURE 10. Station 3, Initial and Peak Bore Surface Temperature for 125 Rounds, Unlined Barrel

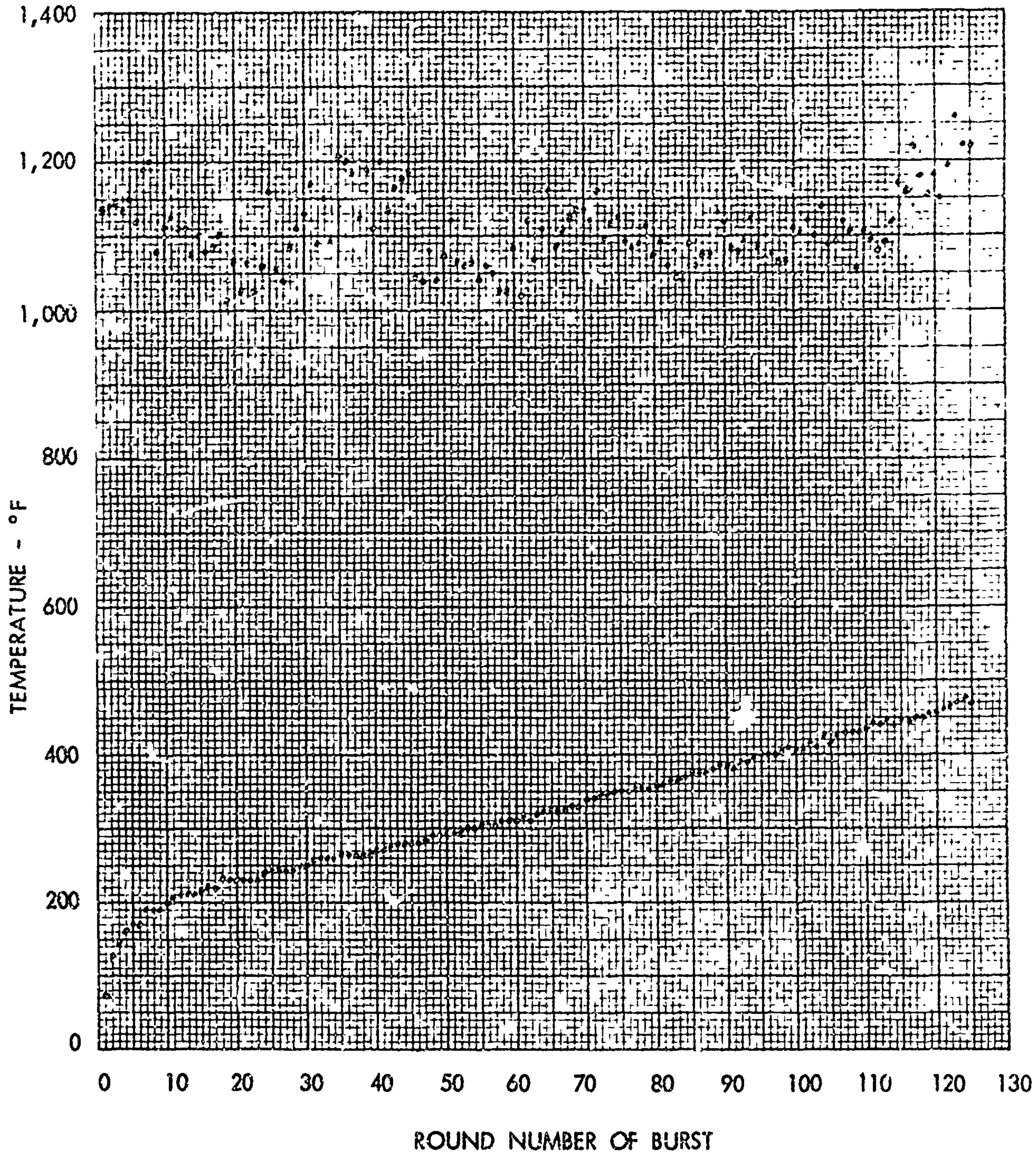


FIGURE 11. Station 4, Initial and Peak Bore Surface Temperatures for 125 Rounds, Unlined Barrel

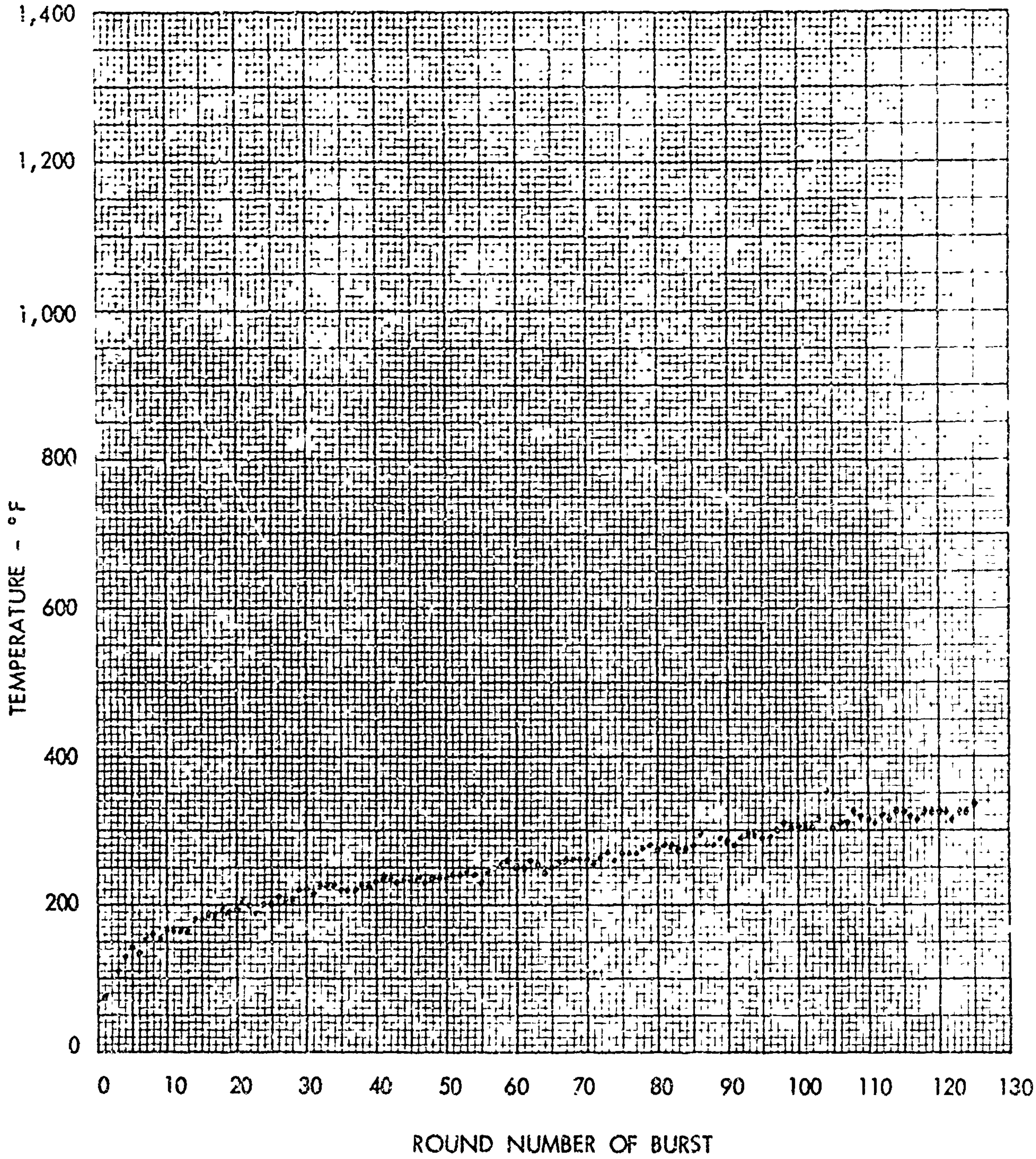


FIGURE 12. Station 5, Initial Bore Surface Temperatures for 125 Rounds, Unlined Barrel

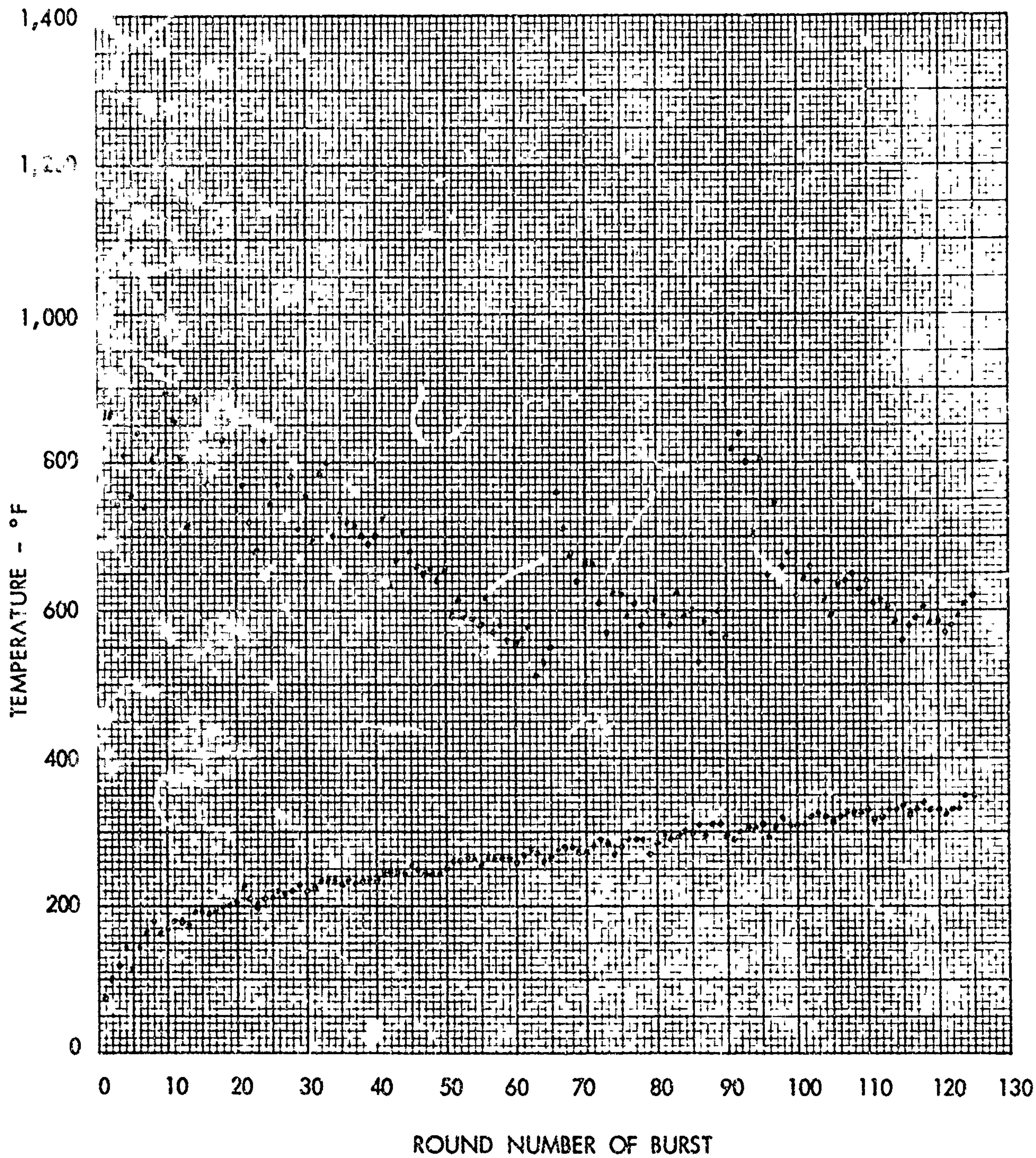


FIGURE 13. Station 6, Initial and Peak Bore Surface Temperatures for 125 Rounds, Unlined Barrel

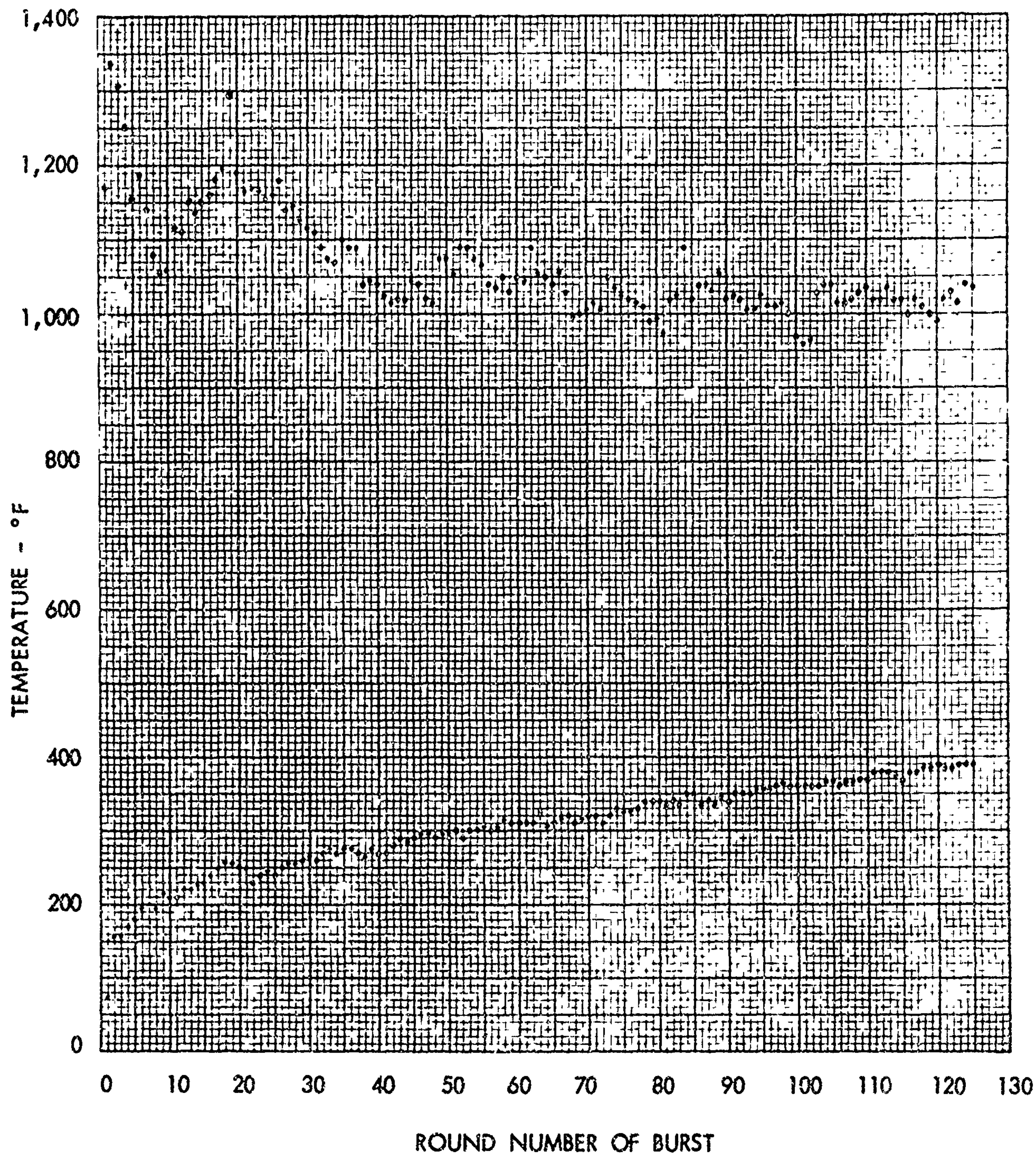


FIGURE 14. Station 1, Initial and Peak Bore Surface Temperatures for 125 Rounds, Lined Barrel

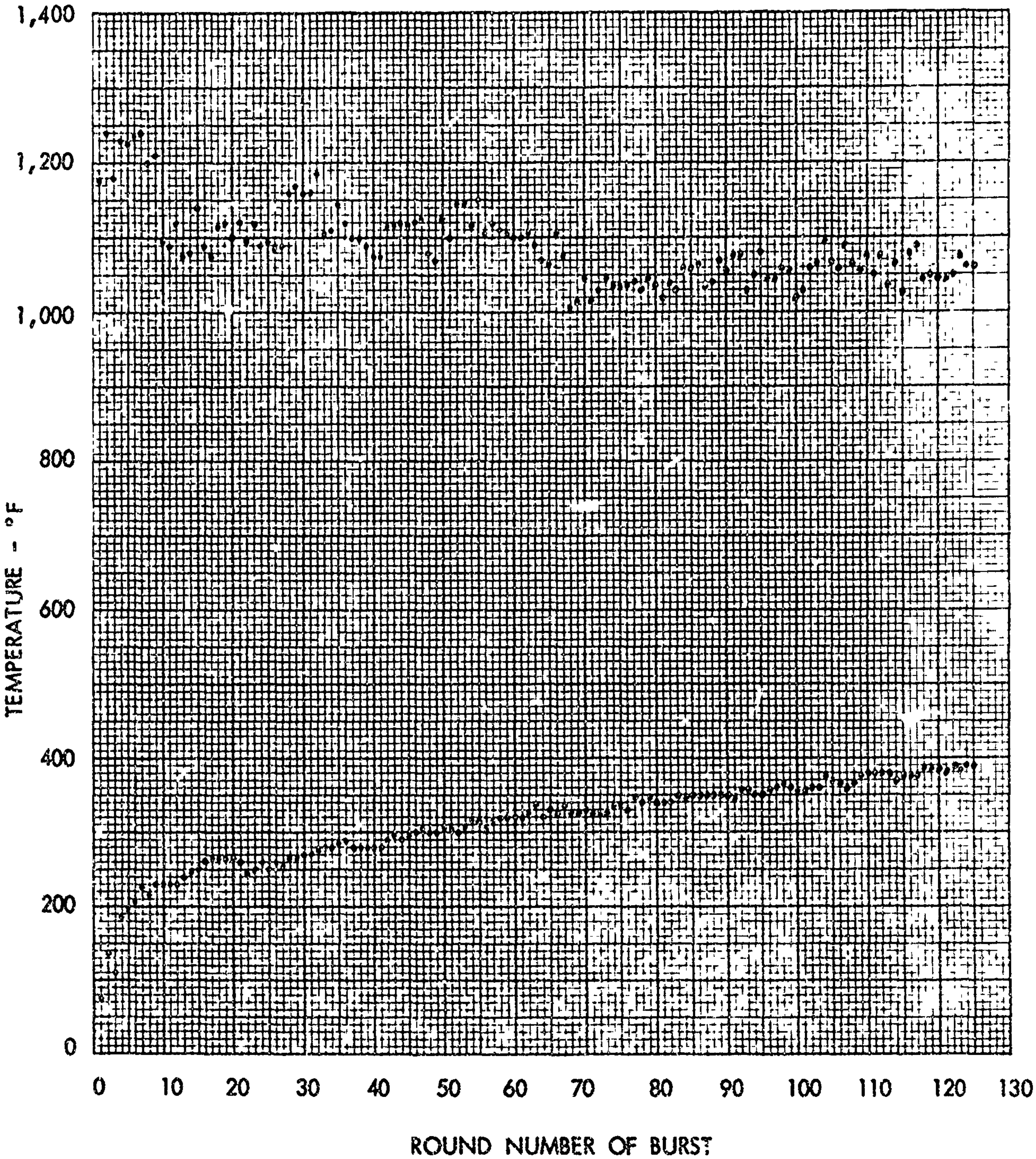


FIGURE 15. Station 2, Initial and Peak Bore Surface Temperatures for 125 Rounds, Lined Barrel

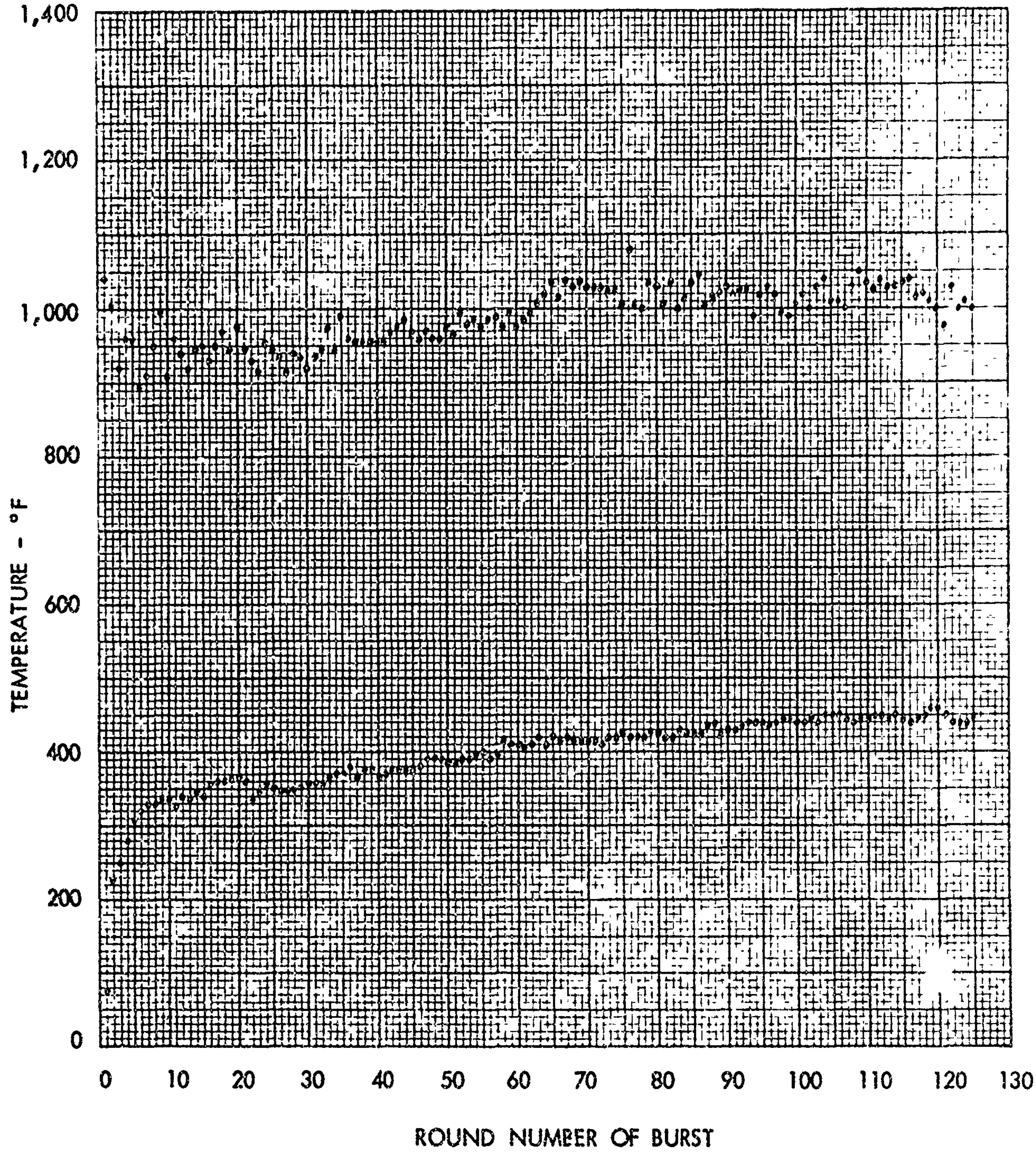


FIGURE 16. Station 3, Initial and Peak Bore Surface Temperatures for 125 Rounds, Lined Barrel

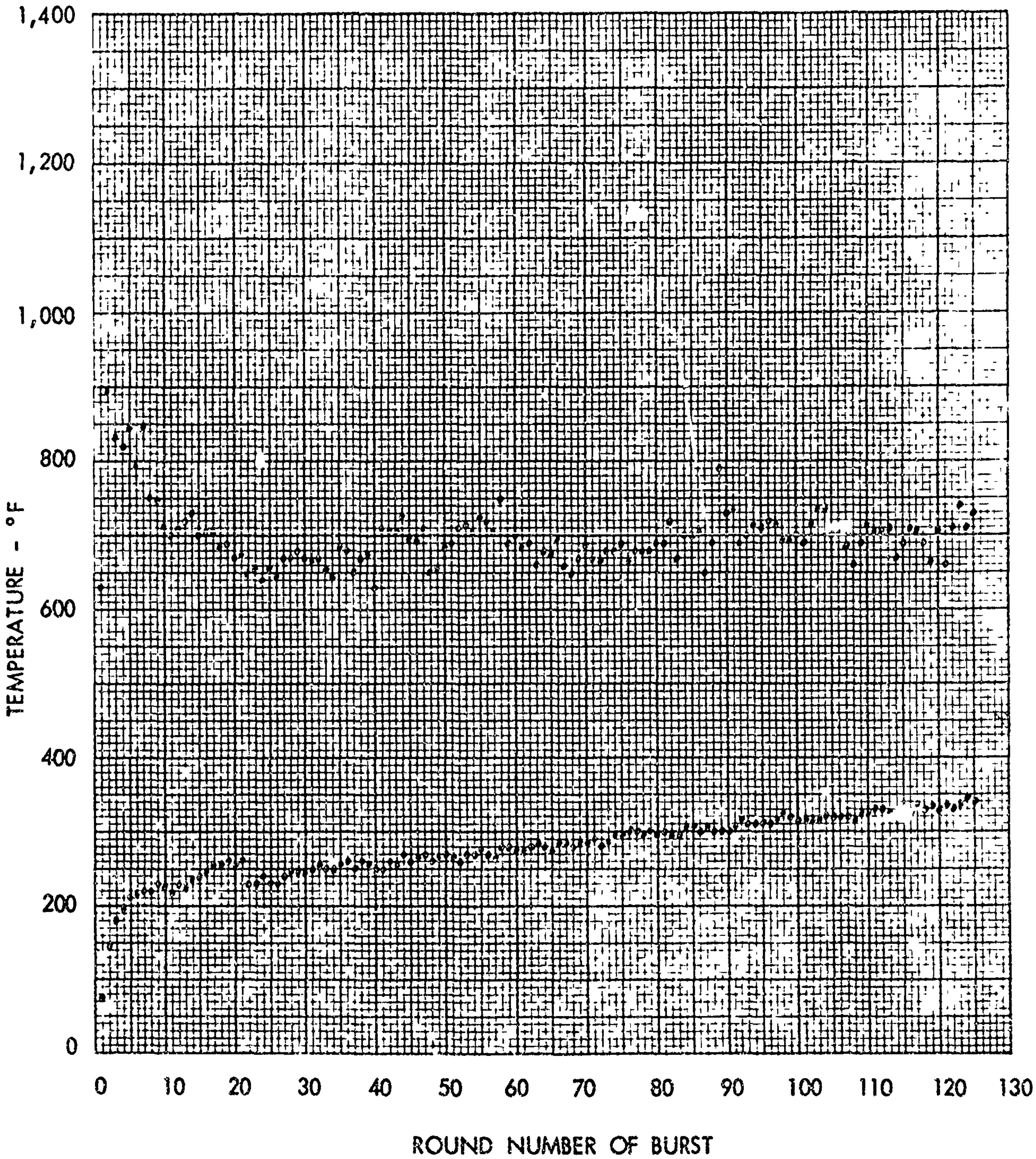


FIGURE 17. Station 5, Initial and Peak Bore Surface Temperatures for 125 Rounds, Lined Barrel

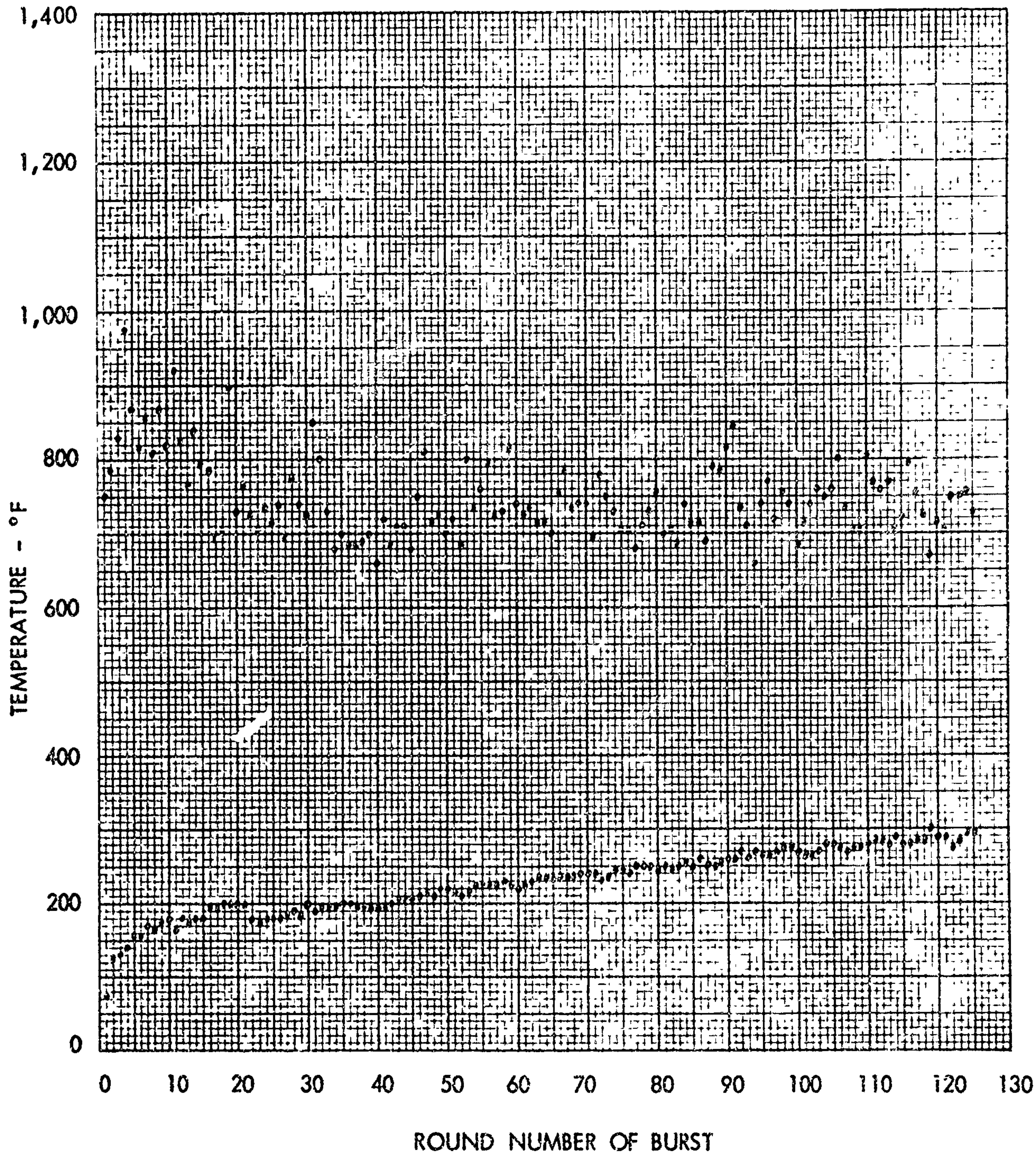


FIGURE 18. Station 6, Initial and Peak Bore Surface Temperatures for 125 Rounds, Lined Barrel

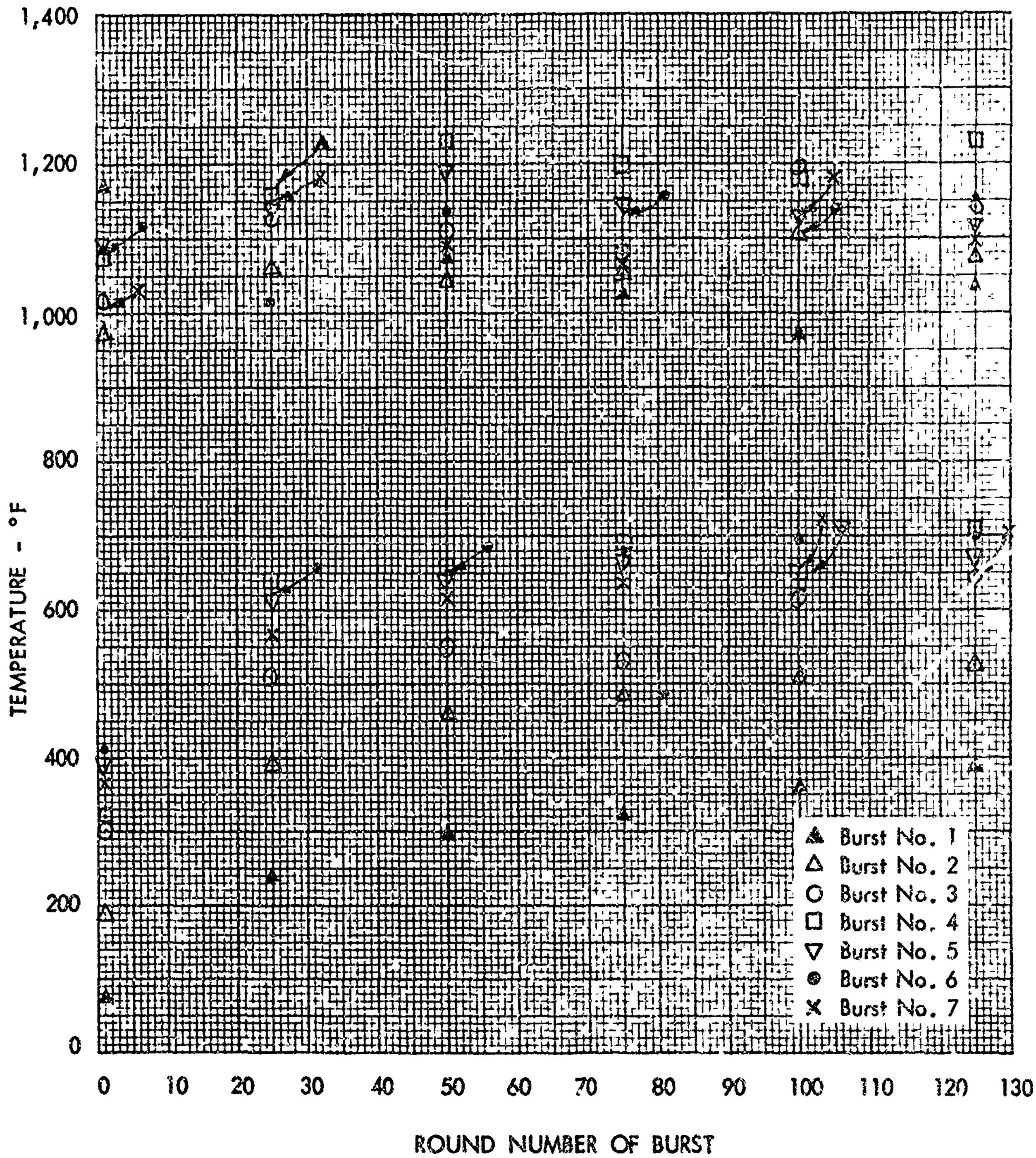


FIGURE 19. Station 1, Initial and Peak Bore Surface Temperatures Every 25th Round, Bursts Nos. 1 through 7

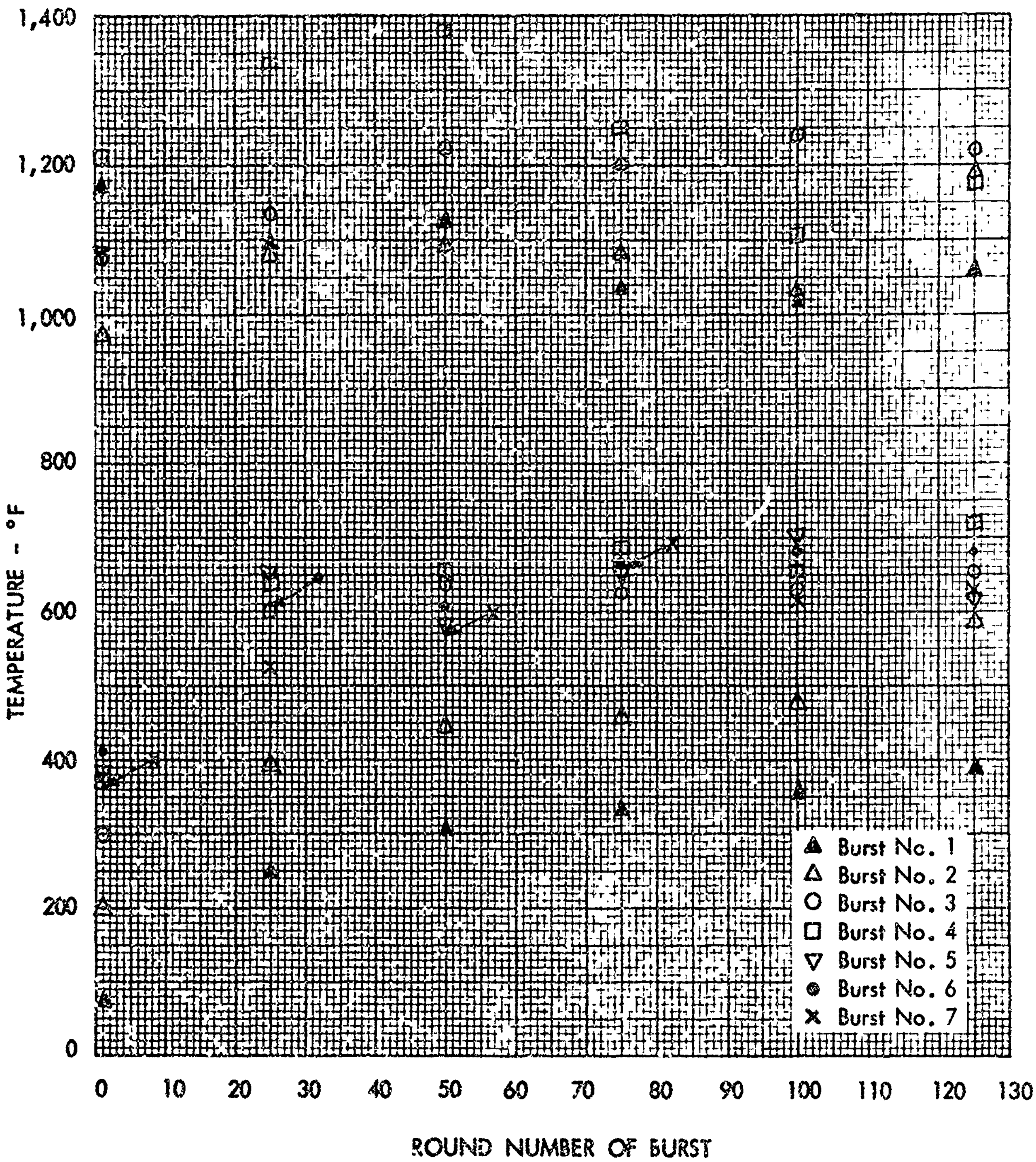


FIGURE 20. Station 2, Initial and Peak Bore Surface Temperatures Every 25th Round, Bursts No. 1 through 7

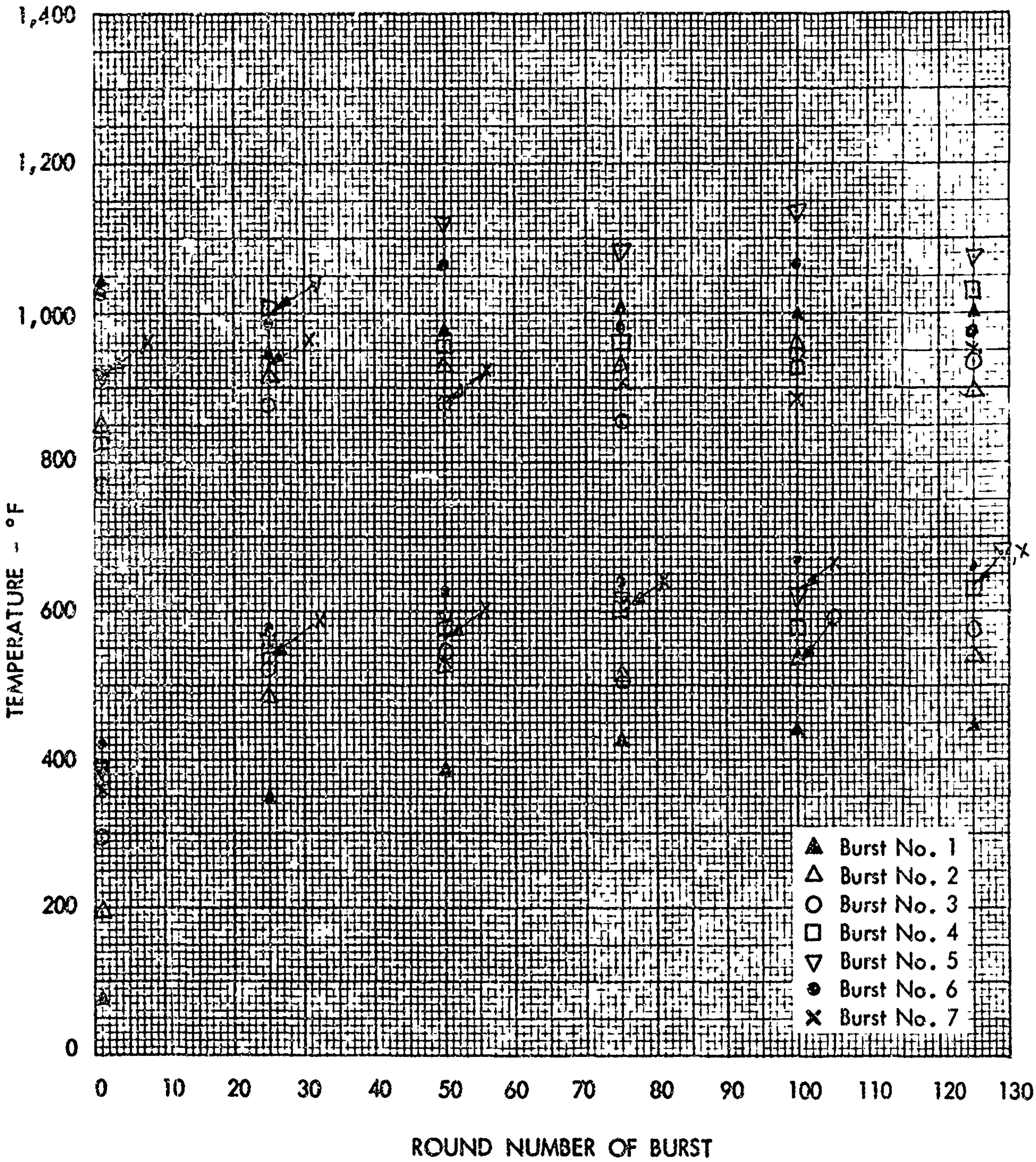


FIGURE 21. Station 3, Initial and Peak Bore Surface Temperatures Every 25th Round, Bursts Nos. 1 through 7

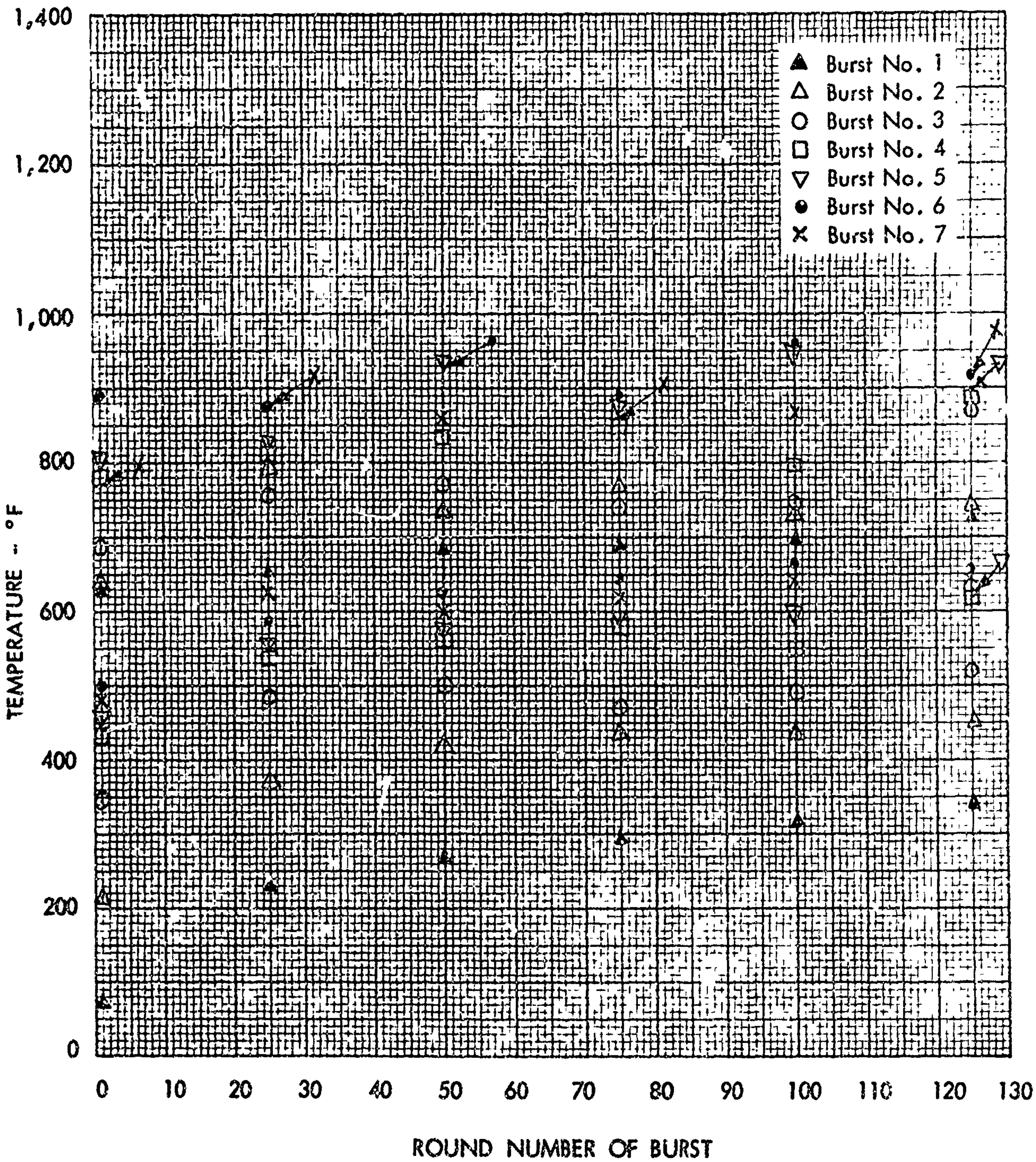


FIGURE 22. Station 5, Initial and Peak Bore Surface Temperatures Every 25th Round, Bursts Nos. 1 through 7

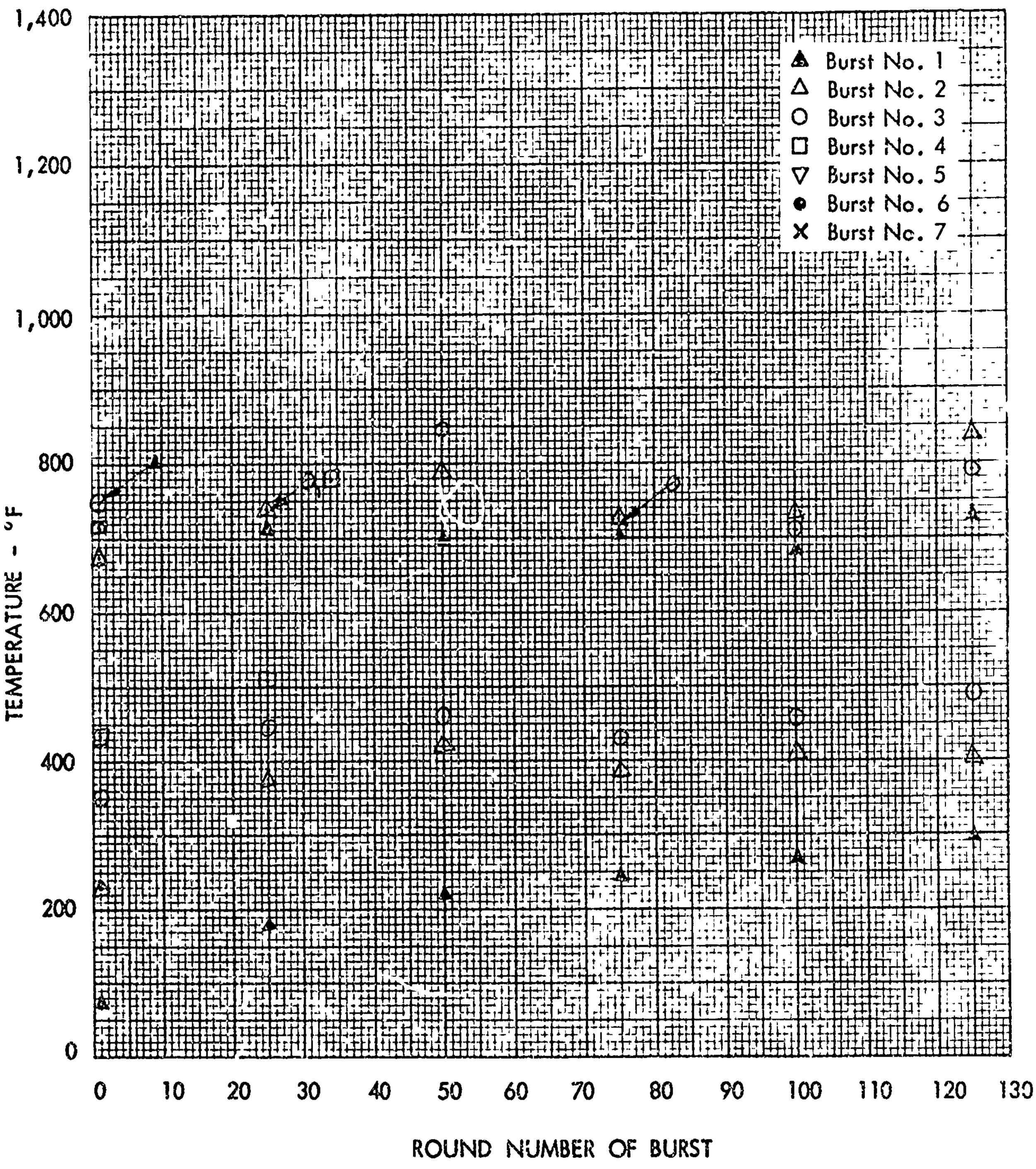


FIGURE 23. Station 6, Initial and Peak Bore Surface Temperatures Every 25th Round, Bursts Nos. 1 through 7

sixth round of the seventh burst and the barrel cooled over 100° during the 2 minutes required to clear the gun.

The results of the bore surface temperature measurements of the two barrels are summarized in Tables II and III. Table II gives the average of the peak values for all the test firings. The initial values just prior to first and last round of each burst are listed in Table III. These initial values indicate the amount of heating during a burst and cooling following the burst.

TABLE II

AVERAGE INDICATED PEAK BORE SURFACE TEMPERATURES DURING BURST

	Thermocouple Stations					
Barrel	1	2	3	4	5	6
Unlined	1137°F	1120°F	1074°F	1108°F	---*	674°F
Lined						
Burst						
No. 1	1064	1090	989	---	698	747
No. 2	1052	1076	913	---	731	751
No. 3	1111	1186	877	---	761	758
No. 4	1179	1242	950	---	826	700
No. 5	1135	---	1055	---	880	---
No. 6	1105	---	1016	---	910	---
No. 7	1089	---	911	---	858	---

* No data obtained.

TABLE III

INITIAL* INDICATED BORE SURFACE TEMPERATURE RISE DURING BURST SEQUENCE

Barrel		Thermocouple Stations 1	2	3	4	5	6
Unlined,	Start	75°F	75°F	75°F	75°F	75°F	75°F
	End	390	380	360	470	335	350
Lined,							
No. 1	Start	75	75	75	---	75	75
	End	390	390	445	---	340	295
No. 2	Start	190	200	195	---	215	230
	End	525	585	540	---	450	405
No. 3	Start	300	300	295	---	345	350
	End	645	655	575	---	520	490
No. 4	Start	320	370	435	---	375	435
	End	710	715	630	---	615	---
No. 5	Start	390	380	385	---	455	---
	End	670	615	635	---	615	---
No. 6	Start	410	410	420	---	500	---
	End	700	680	660	---	655	---
No. 7	Start	365	365	360	---	480	---
	End	645	630	635	---	645	---

* Temperature immediately prior to firing of round.

The external temperatures for both the lined and unlined barrels are plotted in Figure 24. The data are given in Table I of Appendix C. The curves in Figure 24 indicate the firing schedule that was followed and the machine gun that had been jammed after the fifth round of the seventh burst. The maximum external temperature recorded was 977°F at Station 6 at the end of the sixth burst.

A review of all the bore surface temperature data indicates the peak temperatures for each station become stabilized

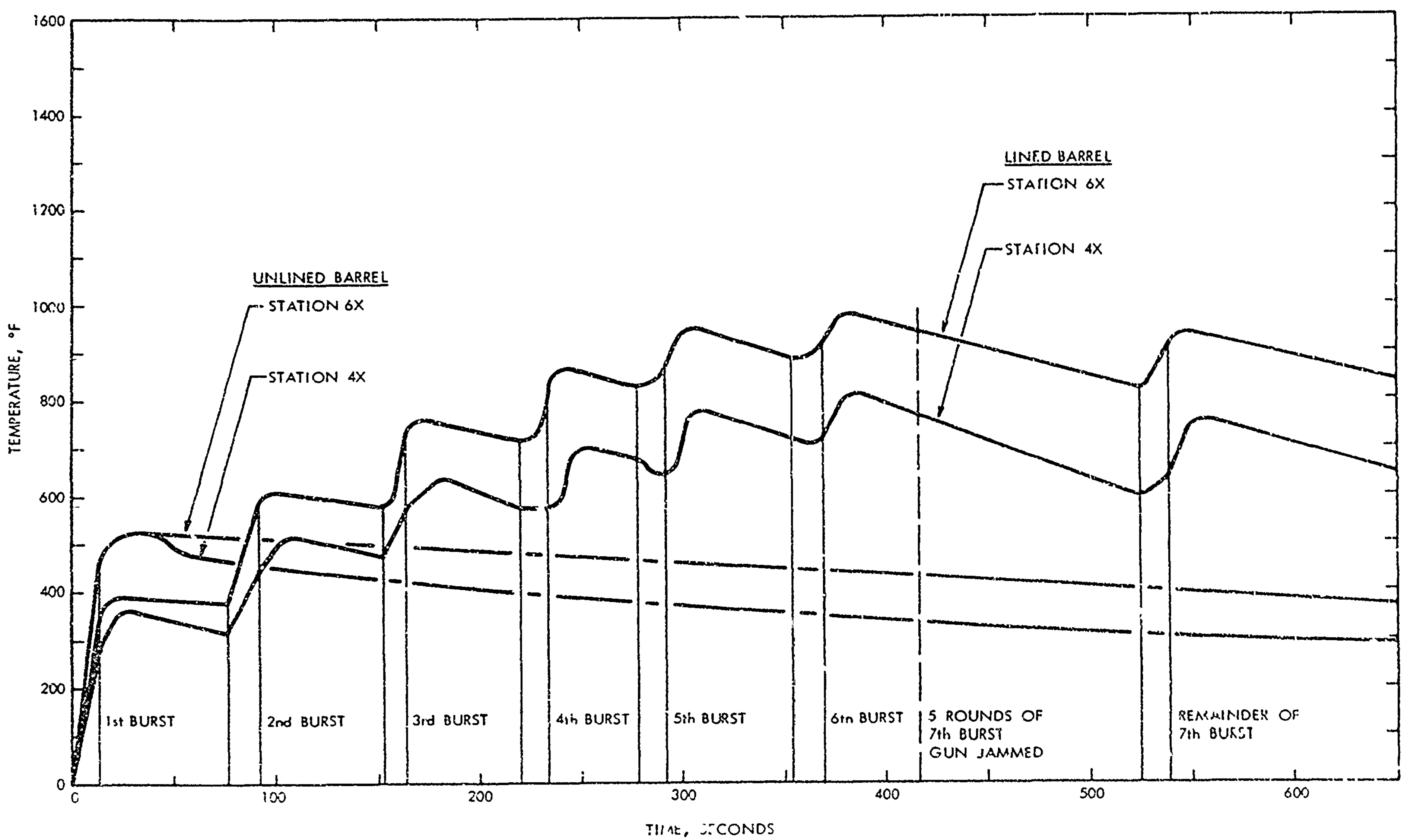


FIGURE 24. External Surface Temperatures of Lined and Unlined M60 Barrels During 125-Round Bursts

following higher values recorded during the first few rounds of the first burst. They do not significantly change from this level during all rounds of subsequent bursts. The indicated peak temperatures fluctuated in a band with less than 200° spread at this level. The fluctuations were not necessarily in phase with those of adjacent stations. These effects indicate the turbulent nature of the propellant gases within the barrel and emphasize the nonuniformity of the charge combustion of one round to the next.

The average of the peak temperatures for each station shows the relative heating effect from the propellant gases at that station. The data in Table II indicate the stations of the liner region near the chamber (Stations 1 through 4) are heated to a significantly higher peak temperature than the outer stations (Stations 5 and 6). Moreover, data from Table III indicate that the initial temperatures (before the next round) of the liner stations were higher than the outer stations at the end of the burst, particularly for the lined barrel.

Several bore surface thermocouples failed during the test firings. The thermocouple for Station 5 of the unlined barrel did not respond to the peak temperatures during the firing of the burst. Its records indicated that the thermal junction was located a short distance below the bore surface and, hence, the rapidly changing surface temperatures could not be sensed. When the temperatures were changing very slowly, such as during cooling, the temperatures at the thermal junction would be nearly identical to those at the bore surface. Hence, the initial bore surface temperatures for Station 5 are reported. This same failure occurred with the thermocouple at Station 2 of the lined barrel during Burst 5. The Alumel wire of the thermocouple at Station 6 of the lined barrel broke from the Alumel extension wire during the 38th round of No. 4 Burst. This resulted in an open circuit which caused the recording channel to pick up signals from the adjacent channels.

The external surface temperatures as shown by Figure 24 indicate a significant difference between the lined and unlined barrels at the end of the 1250 round burst. The stations of the unlined barrel had virtually the same temperatures at the end of the burst (470°F Station 4X and 460°F Station 6X). The temperatures continued to rise after the end of the burst for 16 seconds to 530°F (Station

4X) and for 22 seconds to 525°F (Station 6X). The temperatures of the lined barrel increased to 280° and 355°F at the end of the bursts, and peaked at 360° and 390°F for the respective stations. Thus, the unlined barrel was at least 135° hotter than the lined barrel at the two stations.

The cooling curves for the two barrels are plotted in Figure 24. Station 4 cooled with the highest rate for both barrels. This higher rate was due to the heat conduction from the barrel into the gun receiver. Furthermore, the unlined barrel, which had been previously machined to a bright finish, had a straw color after the burst. The greatest amount of discoloration occurred between the gas vent and Station 6X; this indicated that the barrel was heated to even higher temperatures forward of Station 6X. Thus, heat conduction from this forward position along the barrel would cause Station 6X to be slower in cooling.

The effects of the additional bursts on the external surface temperatures of the lined barrel are indicated in Figure 24. The data indicate that the external surface temperatures were approaching equilibirum temperatures somewhere between 1100° and 1200° for Station 6X, and lower than that for Station 4X.

The data for Station 4X during the fourth, fifth, and sixth bursts indicate that the thermocouple reading was low during the bursts. An examination of the thermocouples following the test firings disclosed that the lock nut by which the thermocouple was clamped against the barrel at Station 4X was only finger-tight. Hence, the thermocouple probably did not have thermal contact during the vibration of firing. At the moment firing ceased, the thermocouple apparently made contact with the hot barrel to give a fairly accurate temperature reading. Its record during Burst 7 indicated that the lock nut must have vibrated down onto the thermocouple to hold it against the barrel.

The external surface thermocouple records indicate the time at which Burst 7 was initiated. The bore surface thermocouple records show considerable electrical noise in the signals even though only five rounds were fired. The gun was cleared after cookoff of two rounds. As soon as the range was cleared (109 sec. after jamming), the remaining 118 rounds of the burst were fired.

The accuracy of the measurements is influenced by several errors which result from: (1) nonlinearization of the calibration curve, (2) reading of the records on the chart paper, (3) mismatch of the thermal diffusivities of the thermocouple and barrel metals, and (4) unknown factors which could not be determined.

The temperatures measured by the bore surface thermocouples were determined by analyses of the recordings on the Visicorder chart paper, whether the signals were recorded directly from the galvanometers of the Visicorder or from the playback tape of the Ampex DAS-100 system. Both systems had every channel calibrated with a 25 mv. signal which was comparable to the maximum signal expected from the thermocouples.

The maximum error due to nonlinearization of the calibration curve was +2.5% and this occurred at the midpoint of the scale (approximately 560°F); at full scale, 25 mv., this error was near zero. The reading error of the records on the chart paper is estimated to be less than ±20°F because a special scale was produced in which the markings were expressed in temperature. The smallest divisions on the scale were 10°F which were 0.023 in. apart. Hence, at 560°F, the combined calibration and reading errors were +34° and -20°F; at 1150°F, ±20°F.

An inherent error occurred during the period of rapidly changing temperatures of the measurements and was related to the simulation of the heat conduction in the bore surface thermocouples to that through the undisturbed wall of the gun barrel. As mentioned in the previous section, the selection of the materials of the thermocouples was made on the basis that the thermal diffusivity of the Chromel/Alumel thermocouples matched that of the gun barrel metals (the Stellite liner and the chromium-molybdenum-vanadium-steel barrel) closer than any other themocouple metal combination. The error resulting from the mismatch of thermal diffusivities can only exist during the time of rapid temperature changes and, in particular, during the few milliseconds after exposure to the propellant gases. After the temperature pulse has dissipated in the barrel wall and the barrel is slowly cooling, this error is negligible. An analytical study of the heat conduction in the barrel with the thermal properties of bore surface thermocouple and the bore surface temperatures as parameters should be made to determine the magnitude of this error. This study

was beyond the scope of the current program; it is being recommended for future studies.

A significant error in the bore surface temperature measurements from unknown factors not related to any of the previously described errors is indicated when the bore surface and the external surface temperatures are compared. At the time immediately prior to firing a burst, the bore surface and the external surface temperatures should be virtually equal because these temperatures have had at least 45 sec. to equalize in the barrel wall. A comparison of these temperatures from Table III and Figure 24 shows that the bore surface temperatures are from 110° to 300°F lower than corresponding external surface temperatures for the lined barrel. Numerical values cannot be given for the unlined barrel because bore surface temperatures were recorded for only a couple of seconds after the burst. However, a corresponding error is apparent from the data. A direct comparison of the temperatures from Table III and Figure 24 for identical stations is not possible because of the failure of the bore surface thermocouples. However, comparison of data from adjacent stations indicates the approximate magnitude of this error. The bore surface thermocouple signals were from 62% at 300°F to 55% at 900°F of their probable true values. The external surface temperatures are considered as the accurate data because the thermocouple and the recording equipment for the external temperatures were more conventional than for the bore surface temperatures and the barrel discoloration due to heating indicated external temperature comparable to the measured ones.

A subsequent calibration test in the laboratory was conducted with an electrical heating element placed within the bore of the unlined barrel to check the calibration of the thermocouples and to determine the possibility of any effects from ground currents. The test was conducted with the same thermocouple cable connected to the barrel in the same manner as was used in the firing tests. The bore surface and the external surface thermocouples were in agreement to within ±1% of each other, and no grounding effects could be detected. Only additional firing tests can determine the cause of the large errors in the bore surface temperature measurements. This error was not apparent during checkout tests and was not discovered until the data of burst-test firings were analyzed

An extended effort was conducted to investigate the anomalies described in the preceding material. The planned approach to the problem was to investigate the bore surface thermocouples after firing bursts of different lengths and to determine the effect on the recording system of common grounding of multiple thermocouples.

The test program consisted of the measurement of the bore surface and the external barrel surface temperatures at one station on a standard lined-barrel of an M60 machine gun and the observation of the effect of firing bursts on the position and physical appearance of the bore surface thermocouple. Single rounds and bursts of 5, 10, 200, and 300 rounds were fired. The same lined barrel, the same receiver, and the same type of ammunition (7.62MM - NATO, ball M80, linked for M60 MG) were used for this test program as was used in the initial program.

Bore surface temperatures were determined from Visicorder records of the type shown in Figure 25. The accuracy of the temperature determination from the records was estimated to be ±20°F.

A plot of bore surface temperatures for Test 12, a 200-round burst, is shown in Figure 26. This test showed the expected characteristic of generally increasing peak and initial bore surface temperatures in contrast to the decreasing temperatures observed in the initial contract work.

A plot of bore surface temperatures for the first 242 rounds of Test 17, a 300-round burst, is shown in Figure 27. This test showed generally decreasing peak temperatures noted in the initial work, but it is unique in that it showed a sudden increase in peak and initial temperatures after the 80th round.

A log of the tests is contained in Appendix D of this report. All indications of thermocouple recession are estimates made on the basis of comparisons between the known diameter of the bore surface thermocouple and the position of the thermocouple surface with respect to the bore surface. The comparison was made by observation through a borescope.

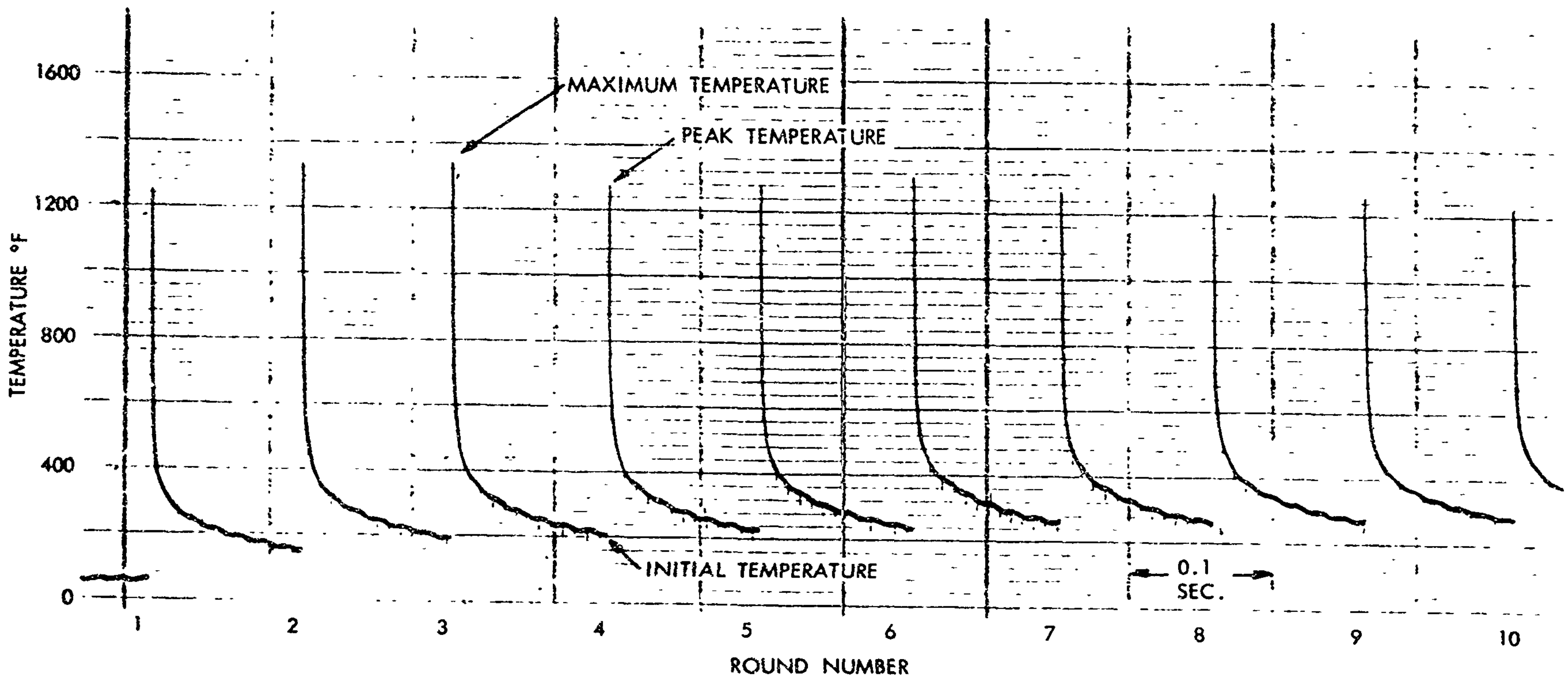


FIGURE 25. Typical Record of Bore Surface Temperature

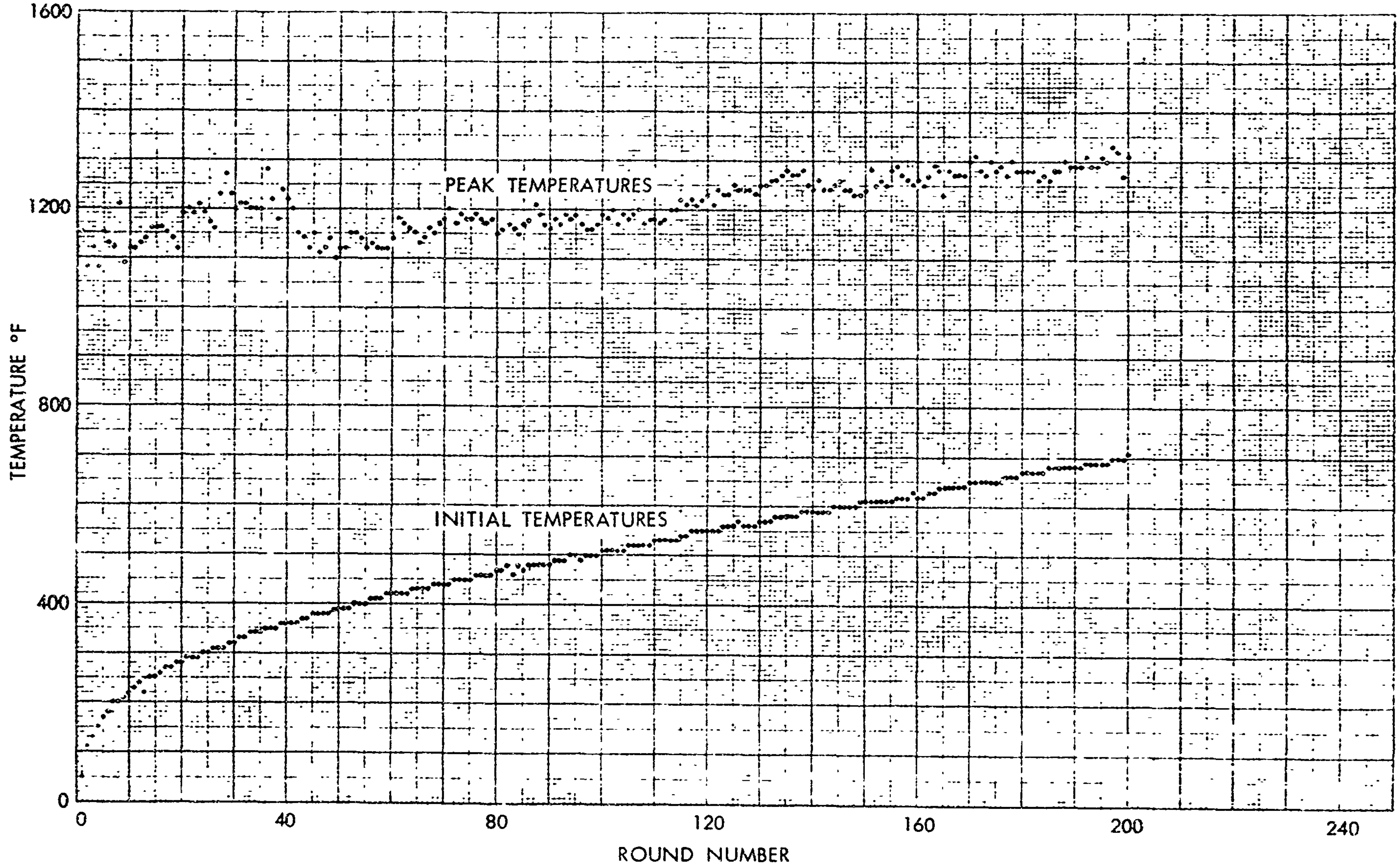


FIGURE 26. Peak and Initial Temperatures Recorded for Test No. 12

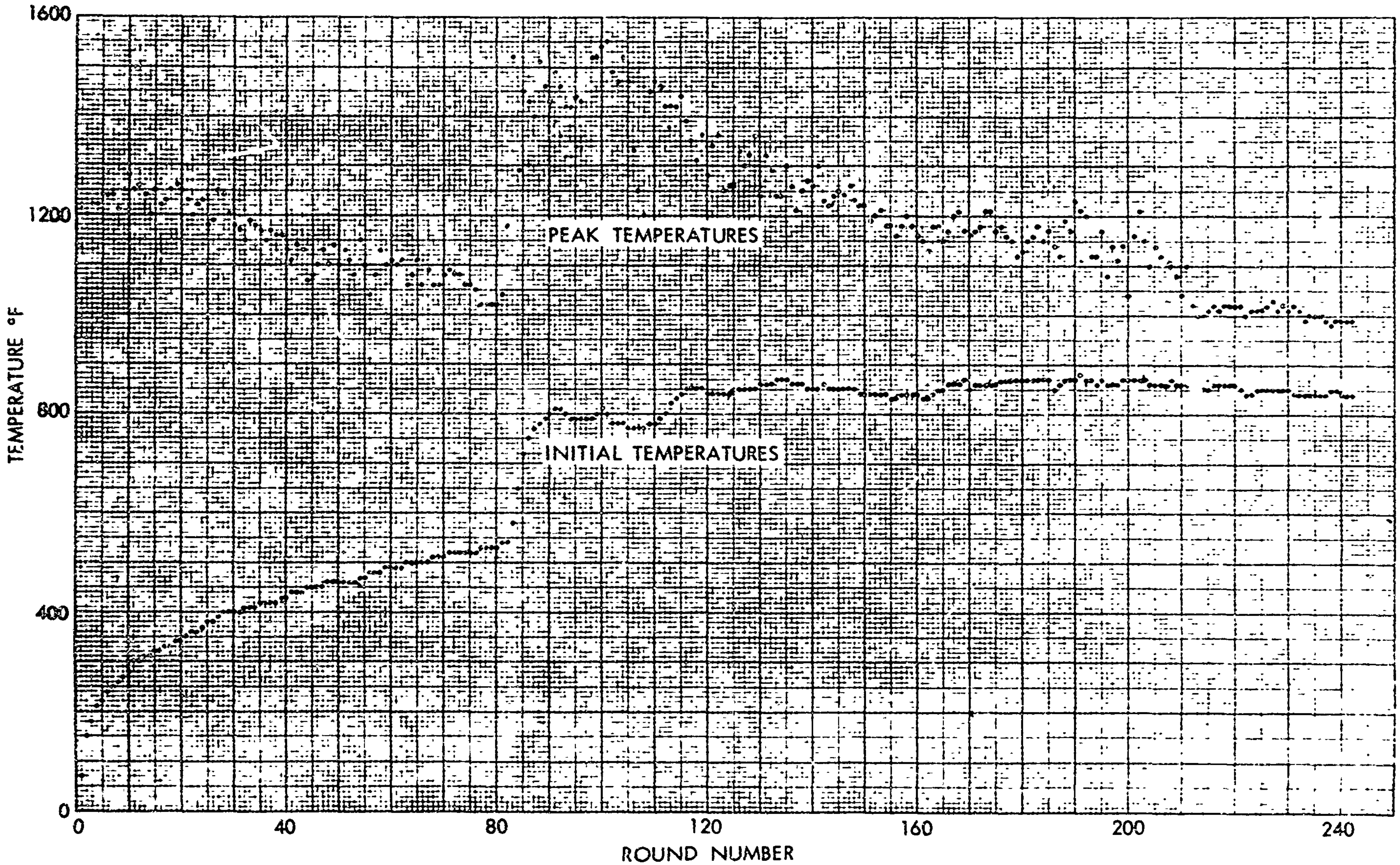


FIGURE 27. Peak and Initial Temperatures Recorded for Test No. 17

The following observations were made after examination of the data recorded:

1. The tip of each Chromel/Alumel bore surface thermocouple was generally displaced 0.002 to 0.005 in. from the original position after bursts of 1 to 5 rounds and 0.003 to 0.010 in. after bursts of 10 rounds or more.

2. The tip of each bore surface thermocouple was coated with a copper colored material presumably stripped from the jackets of projectiles.

3. The tip of each bore surface thermocouple and the adjacent surface of the bore were coated with a sooty deposit after each burst.

4. A new or freshly cleaned Chromel/Alumel bore surface thermocouple indicates peak temperatures of 1400° to 1450° within the first 5 rounds of usage. Tests 5, 6, and 15 illustrate this effect.

5. The maximum bore surface temperature recorded was 1550°F (the 101st round of Test 17, a 300-round burst.

The observed tip recession of the bore surface thermocouples indicates that the peak firing pressures promote plastic deformation. Such plastic deformation can result in failure of the thin layer of insulation between the inner wire and the sheath. Insulation failure forms an effective junction well back from the bore surface. The effect is to indicate temperatures more representative of conditions at the internal copper seal than at the bore surface.

Coating of the thermocouple junction with copper and soot will change the effective depth of the junction below the bore surface. The thermal diffusivity of the coating is considerably different from that of the barrel material.

On Tests 5 through 17, the bore surface thermocouple was adjusted to be flush with the bore of the barrel before each test. No such adjustment was made in the work of the initial contract.

The sudden increase in peak and initial bore surface temperatures at the 82nd round of Test 17 (Figure 27) is believed to be caused by the loosening and the blowing away of a coating which had accumulated on the thermocouple face. The records of the next 20 rounds are believed to be true readings of the bore surface temperatures.

On the basis of the above observations, Figure 28 has been prepared showing an estimate of the actual bore surface temperatures for Test 17. Two curves, having the same slopes and separation as those recorded for Test 12 (Figure 26) were adjusted to pass through the maximum recorded temperatures of Test 17.

CONCLUSIONS

The following conclusions are drawn from the work accomplished:

1. Multichannel recordings of bore surface and external surface temperatures made during the initial contract period contain errors of unknown magnitude. The errors are due to accumulations of foreign materials over the bore surface thermocouples and interaction between recorder channels when connected to multiple thermocouples which are all electrically connected to the gun barrel at points not necessarily at the same temperature.

2. Single channel recordings of bore surface temperature produced consistently higher records of peak and initial temperatures than did multichannel recordings made during the initial contract period.

3. External surface temperatures measured on an electrically isolated potentiometer were in agreement with single channel recordings of bore surface temperatures after temperatures have equalized following the end of a burst of fire.

4. Peak bore surface temperature, near the rifling origin, can be expected to exceed 1400°F during the first few rounds of a burst.

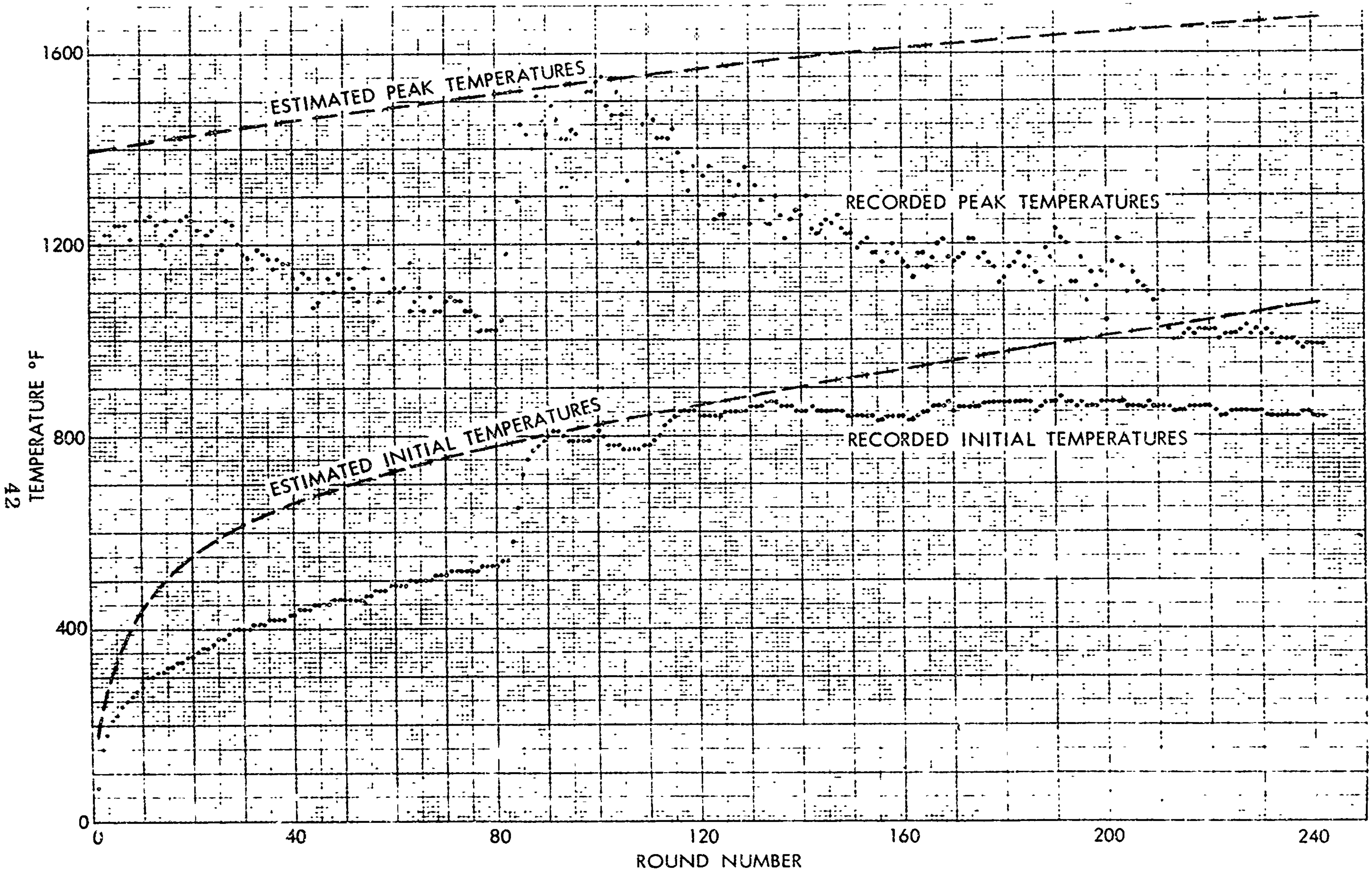


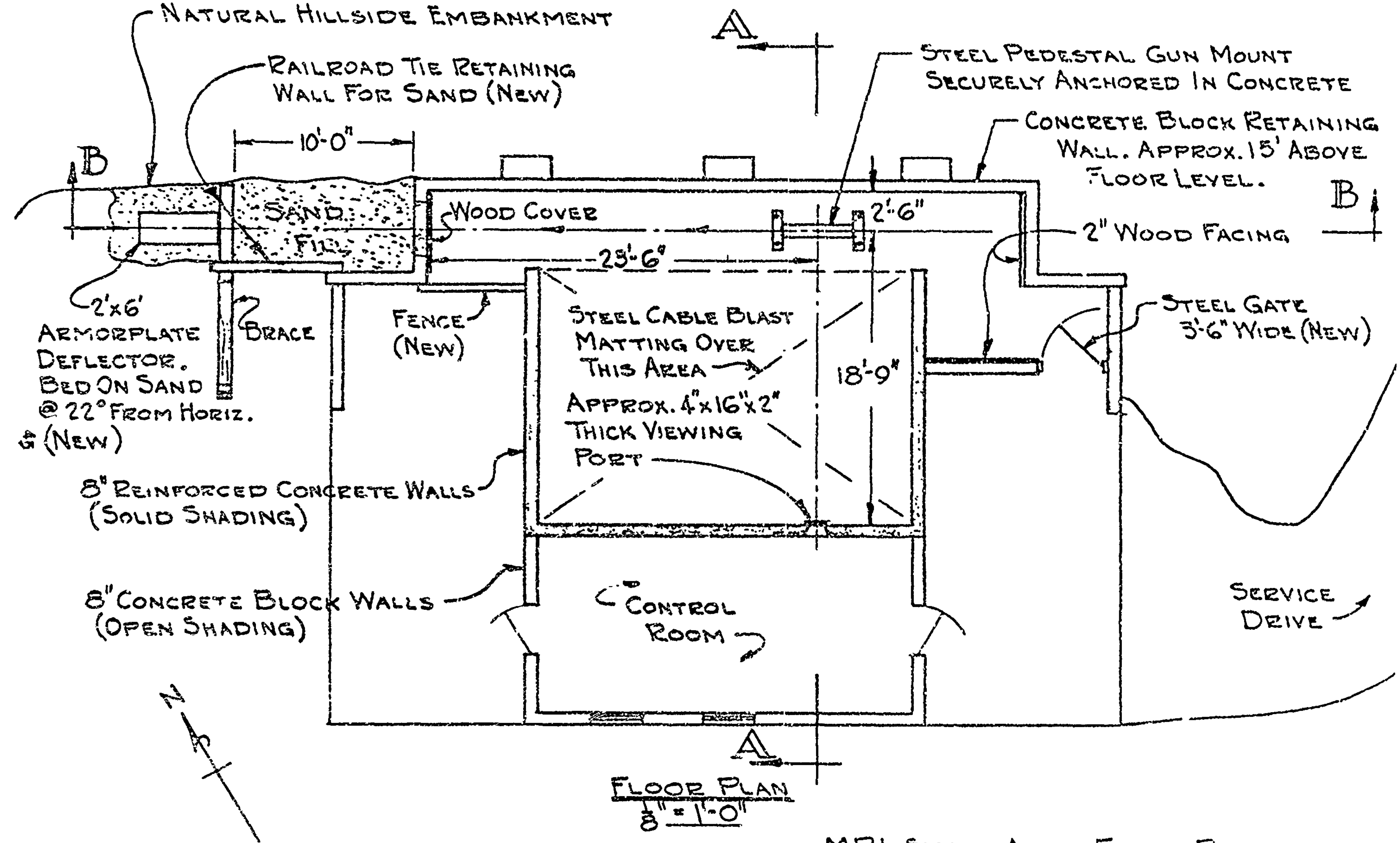
FIGURE 28. Estimated and Recorded Bore Surface Temperatures for Test No. 17

5. Peak bore surface temperature, near the rifling origin, can be expected to exceed $1500^{\circ}F$ after 100 rounds of continuous firing.

6. Thermocouple materials more suitable than Chromel and Alumel are required for bore surface temperature measurements.

APPENDIX A

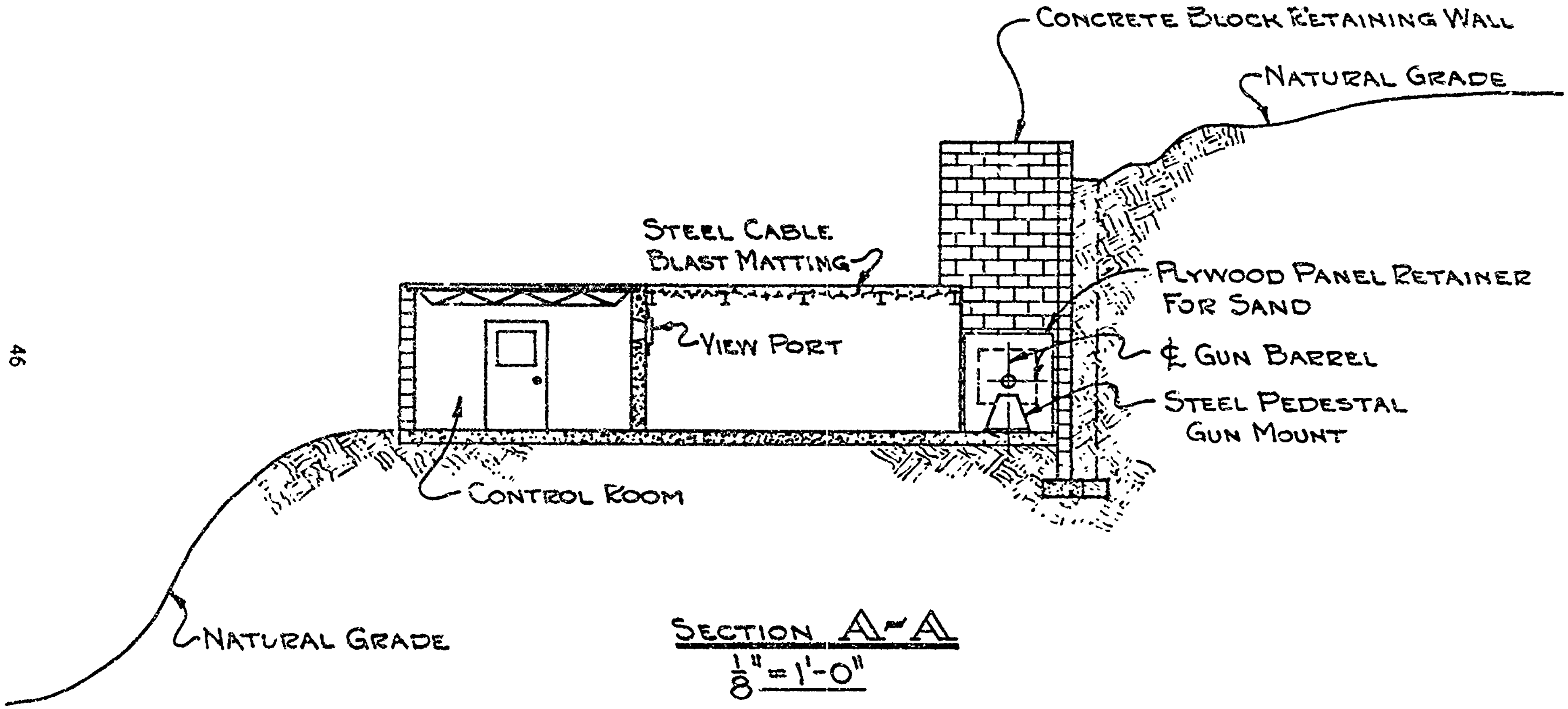
FLOOR PLAN AND ELEVATIONS OF THE MRI RANGE FACILITY AT THE DERAMUS FIELD STATION, GRANDVIEW, MISSOURI



Floor Plan
$\frac{1}{8}$" = 1'-0"

MR1 Small Arms Firing Range
Deramus Field Station
Grandview, Mo.

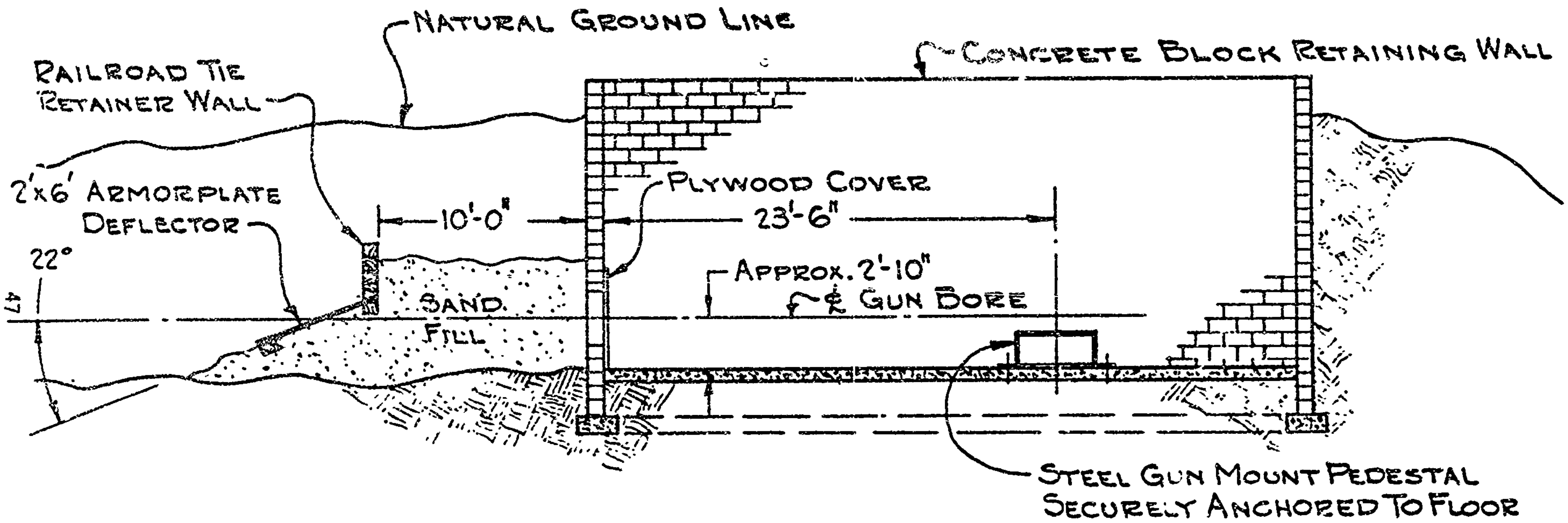
WH 12-69



SECTION A–A
$\frac{1}{8}'' = 1'\text{-}0''$

MR1 SMALL ARMS FIRING RANGE
DERAMUS FIELD STATION
GRANDVIEW, MO.

WH 12-69



Section B-B
1/8" = 1'-0"

MRI Small Arms Firing Range
Deramus Field Station
Grandview, Mo.

WH 69

APPENDIX B

TABLE I - INITIAL AND PEAK BORE SURFACE TEMPERATURES, UNLINED BARREL, 125-ROUND BURST

TABLE II - INITIAL AND PEAK BORE SURFACE TEMPERATURES, LINED BARREL, FIRST 125-ROUND BURSTS

TABLE III - INITIAL AND PEAK BORE SURFACE TEMPERATURES, LINED BARREL, AT EVERY 25 ROUNDS OF BURSTS NOS. 2 THROUGH 7

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TABLE I

INITIAL AND PEAK BORE SURFACE TEMPERATURES, UNLINED BARREL, 125-ROUND BURST
DATA OF JUNE 4, 1970

Round	Station 1 Temperature °F	Station 2 Temperature °F	Station 3 Temperature °F	Station 4 Temperature °F	Station 5 Temperature °F	Station 6 Temperature °F
1 I	75	75	75	75	75	75
P	1170	1190	1065	1135	-*	865
2 I	85	90	90	128		100
P	1170	1190	1065	1140	-	865
3 I	110	110	110	145	110	120
P	1225	1260	1060	1145	-	145
4 I	125	130	125	160	130	145
P	1220	1210	1090	1135	-	810
5 I	150	150	135	170	145	165
P	1200	1205	1135	1150	-	755
6 I	145	145	135	170	135	145
P	1215	1150	1060	1120	-	840
7 I	150	165	150	190	155	165
P	1245	1230	1100	1190	-	740
8 I	160	170	160	190	160	180
P	1195	1230	1155	1200	-	805
9 I	160	160	155	190	155	165
P	1215	1130	1145	1080	-	815
10 I	170	170	165	200	165	170
P	1210	1185	1145	1110	-	895
11 I	170	165	160	205	165	180
P	1185	1150	1145	1125	-	855
12 I	165	170	170	210	165	180
P	1150	1145	1140	1110	-	805
13 I	180	175	175	210	165	175
P	1185	1145	1115	1110	-	715
14 I	185	185	180	210	180	195
P	1165	1080	1080	1075	-	885
15 I	190	190	185	215	180	195
P	1160	1120	1070	1100	-	785
16 I	190	180	180	220	185	190
P	1135	1110	1090	1080	-	770
17 I	195	195	185	220	185	195
P	1220	1140	1090	1085	-	860
18 I	200	195	195	225	195	200
P	1160	1220	1145	1105	-	830
19 I	205	195	190	230	190	200
P	1180	1090	1060	1015	-	855
20 I	200	200	195	230	195	205
P	1110	1125	1050	1065	-	860
21 I	210	205	200	230	205	225
P	1160	1110	1045	1025	-	770
22 I	210	205	200	230	200	210
P	1120	1090	1065	1065	-	720
23 I	210	195	195	230	190	200
P	1125	1095	1070	1025	-	680
24 I	210	200	200	240	200	210
P	1125	1100	1085	1060	-	830
25 I	205	205	200	245	200	210
P	1170	1140	1100	1160	-	745

* Failed to give peak temperatures.

TABLE I (continued)

Round		Station 1 Temperature °F	Station 2 Temperature °F	Station 3 Temperature °F	Station 4 Temperature °F	Station 5 Temperature °F	Station 6 Temperature °F
26	I	210	210	210	245	210	220
	P	1130	1160	1090	1055	-	770
27	I	210	215	205	245	205	215
	P	1110	1145	1060	1040	-	730
28	I	215	205	210	245	205	220
	P	1195	1120	1080	1085	-	780
29	I	235	220	220	250	220	230
	P	1195	1190	1130	1110	-	710
30	I	225	225	220	250	220	220
	P	1130	1125	1015	1130	-	755
31	I	225	215	215	255	215	225
	P	1145	1130	1060	1170	-	695
32	I	230	230	225	260	225	235
	P	1150	1135	1125	1090	-	785
33	I	230	220	225	260	225	235
	P	1195	1180	1115	1150	-	800
34	I	230	220	220	260	225	235
	P	1110	1110	1085	1095	-	700
35	I	235	230	215	265	220	230
	P	1115	1095	1075	1205	-	730
36	I	240	230	225	265	220	235
	P	1170	1120	1070	1200	-	720
37	I	240	235	225	265	220	230
	P	1185	1110	1075	1185	-	715
38	I	245	240	225	265	225	235
	P	1110	1105	1075	1125	-	700
39	I	250	240	230	265	225	235
	P	1130	1145	1105	1190	-	690
40	I	250	240	230	270	230	235
	P	1150	1120	1110	1110	-	700
41	I	260	245	240	270	235	245
	P	1145	1125	1065	1200	-	725
42	I	250	245	240	275	235	245
	P	1130	1095	1090	1135	-	635
43	I	240	240	230	280	230	245
	P	1140	1145	1065	1165	-	670
44	I	255	240	235	280	235	245
	P	1110	1115	1110	1175	-	705
45	I	260	250	245	280	235	255
	P	1160	1120	1095	1085	-	680
46	I	265	255	240	280	235	250
	P	1160	1135	1095	1045	-	660
47	I	255	255	245	285	230	245
	P	1135	1125	1075	1040	-	650
48	I	255	255	240	290	235	245
	P	1135	1105	10[illegible]	1080	-	655
49	I	270	255	245	290	235	245
	P	1150	1135	1120	1040	-	640
50	I	265	260	245	295	235	250
	P	1135	1150	1085	1075	-	655

TABLE I (continued)

Round		Station 1 Temperature °F	Station 2 Temperature °F	Station 3 Temperature °F	Station 4 Temperature °F	Station 5 Temperature °F	Station 6 Temperature °F
51	I	265	260	250	295	240	260
	P	1165	1155	1050	1120	-	595
52	I	270	260	250	295	240	260
	P	1155	1080	1080	1065	-	615
53	I	280	265	260	300	245	265
	P	1150	1145	1080	1060	-	590
54	I	280	270	255	300	240	265
	P	1125	1100	1110	1065	-	590
55	I	280	255	255	305	230	255
	P	1110	1125	1060	1040	-	580
56	I	270	270	255	305	245	265
	P	1180	1135	1065	1060	-	620
57	I	290	270	260	305	250	265
	P	1145	1125	1100	1050	-	570
58	I	270	275	270	310	255	265
	P	1125	1140	1160	1025	-	580
59	I	285	275	265	310	260	265
	P	1105	1055	1105	1025	-	560
60	I	285	265	260	310	250	260
	P	1175	1110	1045	1085	-	555
61	I	290	270	270	315	250	270
	P	1160	1145	1080	1020	-	560
62	I	295	285	275	310	260	275
	P	1175	1105	1060	1120	-	575
63	I	285	285	270	320	255	270
	P	1130	1145	1080	1070	-	510
64	I	290	275	260	325	245	260
	P	1110	1130	1090	1110	-	530
65	I	290	285	265	325	250	265
	P	1160	1200	1085	1160	-	550
66	I	295	285	280	325	255	275
	P	1155	1125	1060	1085	-	760
67	I	295	275	275	325	260	280
	P	1140	1130	1040	1105	-	720
68	I	290	285	270	330	260	280
	P	1140	1100	1075	1125	-	675
69	I	295	290	285	330	260	275
	P	1145	1120	1050	1135	-	640
70	I	305	285	280	340	260	275
	P	1140	1105	1070	1135	-	665
71	I	305	285	280	340	255	280
	P	1150	1120	1080	1120	-	665
72	I	320	295	290	345	265	290
	P	1140	1130	1130	1160	-	610
73	I	305	305	295	345	270	285
	P	1100	1140	1075	1095	-	570
74	I	305	290	285	350	260	270
	P	1195	1080	1030	1115	-	625
75	I	310	300	290	350	270	280
	P	1125	1060	1120	1125	-	625

TABLE 1 (Continued)

Round		Station 1 Temperature °F	Station 2 Temperature °F	Station 3 Temperature °F	Station 4 Temperature °F	Station 5 Temperature °F	Station 6 Temperature °F
76	I	320	305	295	350	270	290
	P	1170	1180	1055	1095	-	595
77	I	315	300	295	355	270	290
	P	1120	1100	1065	1085	-	610
78	I	310	300	295	355	275	290
	P	1095	1050	1050	1090	-	580
79	I	305	295	285	355	280	270
	P	1165	1075	1080	1115	-	600
80	I	320	305	295	360	275	285
	P	1120	1120	1080	1075	-	615
81	I	325	310	305	360	280	295
	P	1130	1125	1105	1095	-	595
82	I	320	305	300	365	280	290
	P	1100	1070	1055	1060	-	580
83	I	330	300	300	365	275	295
	P	1160	1085	1030	1045	-	625
84	I	325	310	295	370	275	300
	P	1155	1110	1080	1040	-	555
85	I	335	320	310	375	280	300
	P	1155	1085	1060	1090	-	600
86	I	330	315	300	375	295	310
	P	1090	1050	1030	1060	-	530
87	I	320	310	300	375	280	295
	P	1100	1075	1040	1075	-	585
88	I	330	310	300	380	280	305
	P	1100	1110	1030	1075	-	570
89	I	335	325	305	385	290	310
	P	1100	1145	1120	1133	-	600
90	I	335	315	305	385	285	295
	P	1125	1085	1035	1120	-	565
91	I	325	310	300	380	280	290
	P	1115	1075	995	1085	-	820
92	I	330	325	305	390	290	300
	P	1135	1105	1085	1080	-	840
93	I	330	320	310	390	295	305
	P	1150	1150	1100	1095	-	800
94	I	330	310	305	395	295	305
	P	1100	1100	1055	1125	-	705
95	I	330	320	310	400	290	310
	P	1090	1080	1050	1085	-	705
96	I	335	315	305	400	290	295
	P	1110	1110	1045	1070	-	650
97	I	340	325	315	400	300	305
	P	1120	1090	1075	1075	-	745
98	I	355	340	330	405	310	320
	P	1185	1125	1090	1065	-	660
99	I	350	340	320	410	305	310
	P	1125	1110	1085	1065	-	680
100	I	350	335	320	405	305	310
	P	1100	1085	1090	1110	-	620

TABLE I (concluded)

Round	Station 1 Temperature °F	Station 2 Temperature °F	Station 3 Temperature °F	Station 4 Temperature °F	Station 5 Temperature °F	Station 6 Temperature °F
101 I	355	335	320	405	305	310
P	1115	1120	1150	1105	-	645
102 I	355	350	300	415	305	320
P	1135	1140	1095	1120	--	660
103 I	350	340	335	420	315	325
P	1095	1080	1070	1100	-	640
104 I	355	345	335	425	355	320
P	1090	1065	1045	1140	-	615
105 I	355	340	325	415	305	315
P	1100	1090	1030	1090	-	595
106 I	350	340	330	425	310	320
P	1085	1105	1035	1095	-	635
107 I	355	345	355	430	310	325
P	1125	1135	1060	1120	-	640
108 I	355	350	335	430	325	325
P	1085	1090	1075	1105	-	650
109 I	360	340	335	430	320	325
P	1100	1100	1080	1055	-	630
110 I	355	350	335	435	315	330
P	1060	1130	1020	1105	-	640
111 I	355	340	335	445	310	315
P	1060	1090	1040	1095	-	610
112 I	315	345	335	440	320	320
P	1065	1110	1035	1080	-	615
113 I	365	355	340	445	315	330
P	1080	1105	1020	1090	-	605
114 I	365	355	345	440	325	330
P	1085	1040	1025	1120	-	585
115 I	360	350	345	450	325	335
P	1065	1135	1020	1170	-	560
116 I	360	360	350	445	320	325
P	1100	1035	1025	1160	-	580
117 I	365	355	340	450	315	330
P	1135	1160	1055	1220	-	590
118 I	380	365	345	450	325	340
P	1135	1135	1110	1180	-	605
119 I	375	360	345	455	325	330
P	1080	1060	1010	1155	-	585
120 I	375	360	345	455	325	330
P	1100	1045	1015	1180	-	585
121 I	370	360	340	460	325	325
P	1050	1105	1050	1150	-	570
122 I	360	350	340	465	315	330
P	1080	1100	1030	1195	-	580
123 I	375	355	345	470	325	330
P	1085	1120	1015	1260	-	595
124 I	380	365	355	475	325	350
P	1115	1085	1060	1220	-	610
125 I	390	380	360	470	335	350
P	1140	1085	1035	1220	-	620

TABLE II

INITIAL AND PEAK BORE SURFACE TEMPERATURES, LINED BARREL, FIRST 125-ROUND BURSTS
DATA OF JUNE 5, 1970

Round		Station No. 1	2	3	5	6
1	I	75	75	75	75	75
	P	1170	1175	1040	630	750
2	I	155	135	225	145	125
	P	1335	1240	1005	895	785
3	I	155	110	250	180	130
	P	1305	1180	920	830	830
4	I	170	185	230	195	140
	P	1250	1230	960	820	975
5	I	180	195	305	210	155
	P	1155	1225	960	845	870
6	I	195	205	320	215	155
	P	1185	1255	895	795	815
7	I	-	225	330	220	170
	P	1140	1240	910	845	855
8	I	195	215	330	220	165
	P	1030	1200	950	750	910
9	I	215	230	335	230	175
	P	1055	1210	995	745	870
10	I	210	230	335	225	180
	P	1060	1095	910	710	820
11	I	210	230	325	220	165
	P	1115	1090	960	700	920
12	I	220	230	340	230	180
	P	1110	1120	940	710	825
13	I	220	240	335	225	175
	P	1150	1075	920	720	765
14	I	225	245	345	235	180
	P	1135	1080	945	730	840
15	I	230	250	340	240	180
	P	1150	1140	950	700	795
16	I	240	260	355	245	195
	P	1160	1090	930	705	785
17	I	250	265	360	255	195
	P	1180	1075	950	705	695
18	I	255	265	360	255	200
	P	1195	1115	970	685	705
19	I	255	265	365	260	200
	P	1295	1120	945	690	900
20	I	250	265	365	255	200
	P	1190	1100	975	670	730
21	I	250	260	360	260	200
	P	1165	1120	945	675	765
22	I	230	245	335	230	180
	P	1170	1095	930	650	725
23	I	240	250	345	230	175
	P	1165	1120	965	655	705
24	I	245	260	355	240	180
	P	1155	1090	955	640	735
25	I	240	250	350	230	180
	P	1160	1095	945	655	715

Round No.		Station No. 1	2	3	5	6
26	I	250	260	345	230	180
	P	1180	1085	935	645	740
27	I	255	255	345	240	185
	P	1140	1090	915	670	695
28	I	255	265	350	245	190
	P	1145	1160	940	670	775
29	I	260	265	350	245	185
	P	1125	1170	935	680	740
30	I	265	270	355	245	200
	P	1115	1160	920	670	725
31	I	260	270	355	250	190
	P	1110	1160	935	665	850
32	I	270	275	355	255	195
	P	1090	1185	945	670	800
33	I	275	280	365	250	195
	P	1075	1105	925	655	730.
34	I	270	280	370	250	195
	P	1070	1110	945	645	680
35	I	275	285	370	255	200
	P	1100	1145	990	685	700
36	I	275	290	380	260	200
	P	1090	1120	960	680	685
37	I	270	280	365	250	195
	P	1090	1100	955	650	685
38	I	265	280	375	260	195
	P	1040	1100	955	670	690
39	I	275	280	375	255	195
	P	1045	1090	955	675	700
40	I	270	280	365	250	195
	P	1040	1075	955	630	660
41	I	270	280	370	250	195
	P	1025	1075	955	710	720
42	I	280	290	375	260	200
	P	1015	1115	970	705	685
43	I	290	295	375	255	205
	P	1020	1115	975	705	710
44	I	285	290	375	270	205
	P	1020	1120	985	725	710
45	I	290	295	375	260	205
	P	1045	1115	970	695	680
46	I	295	300	380	265	210
	P	1040	1120	960	695	750
47	I	295	305	390	270	215
	P	1020	1125	970	710	810
48	I	290	300	390	260	210
	P	1015	1080	960	650	715
49	I	295	300	390	265	220
	P	1075	1070	960	655	725
50	I	295	305	385	270	220
	P	1075	1125	975	685	700

TABLE II (Continued)

Round	Station No. 1	2	3	5	6	Round No.	Station No. 1	2	3	5	6
51 I	300	305	385	265	215	76 I	325	330	420	300	240
P	1055	1100	965	690	720	P	1020	1035	980	665	705
52 I	290	300	390	260	210	77 I	330	345	420	300	250
P	1090	1145	995	710	685	P	1015	1040	1005	680	680
53 I	300	305	330	270	215	78 I	340	340	420	295	250
P	1090	1145	980	715	800	P	1010	1030	1000	680	710
54 I	300	315	395	270	225	79 I	340	345	425	300	250
P	1075	1115	985	705	735	P	990	1045	1035	680	730
55 I	305	315	400	275	225	80 I	340	340	425	295	245
P	1065	1150	975	725	760	P	995	1035	1030	690	755
56 I	300	305	390	270	225	81 I	335	340	420	300	250
P	1040	1105	985	670	695	P	975	1020	1015	690	700
57 I	305	315	395	265	225	82 I	340	340	420	295	245
P	1035	1120	990	705	725	P	1020	1040	1035	720	705
58 I	315	320	415	280	230	83 I	335	350	430	295	250
P	1050	1110	975	650	730	P	1025	1030	1000	670	690
59 I	310	320	410	280	225	84 I	350	345	425	305	255
P	1030	1105	995	690	815	P	1090	1060	1015	700	740
60 I	310	320	410	275	220	85 I	350	350	425	305	250
P	1050	1100	975	700	740	P	1020	1060	1035	700	715
61 I	310	320	405	275	225	86 I	335	350	425	300	260
P	1045	1100	985	685	725	P	1040	1065	1045	705	715
62 I	310	325	410	280	230	87 I	340	350	435	305	250
P	1090	1105	995	690	735	P	1040	1035	1005	650	690
63 I	325	335	420	285	235	88 I	335	350	430	300	250
P	1055	1090	1010	660	715	P	1030	1040	1015	690	790
64 I	305	320	410	280	235	89 I	345	350	425	300	255
P	1050	1070	1020	680	715	P	1055	1070	1020	790	785
65 I	310	330	420	275	235	90 I	340	350	430	300	260
P	1040	1065	1035	675	700	P	1020	1055	1030	730	815
66 I	315	325	415	285	235	91 I	350	345	430	305	260
P	1055	1105	1015	695	755	P	1025	1075	1020	735	845
67 I	320	335	420	285	235	92 I	350	355	435	315	270
P	1030	1075	1040	660	785	P	1020	1075	1025	690	735
68 I	310	325	415	280	235	93 I	350	355	440	310	260
P	995	1005	1030	650	735	P	1005	1030	1025	700	710
69 I	315	325	415	265	240	94 I	355	350	440	310	270
P	1000	1015	1035	670	740	P	1005	1050	990	715	660
70 I	320	330	415	285	240	95 I	355	350	440	310	255
P	1005	1045	1030	685	740	P	1025	1080	1020	710	740
71 I	320	325	415	290	240	96 I	355	355	435	310	265
P	1015	1015	1030	670	695	P	1010	1045	1030	720	770
72 I	310	325	410	280	230	97 I	360	360	440	315	270
P	1005	1030	1030	665	780	P	1010	1045	1020	715	720
73 I	320	325	420	285	235	98 I	365	365	445	325	275
P	1050	1045	1025	680	750	P	1015	1060	995	695	755
74 I	330	335	420	295	245	99 I	360	360	445	320	275
P	1035	1035	1025	680	730	P	1000	1055	990	695	740
75 I	325	335	425	295	245	100 I	360	355	440	315	270
P	1025	1035	1005	690	705	P	970	1020	1015	700	685

TABLE II (Concluded)

Round No.		Station No. 1	2	3	5	6
101	I	360	355	440	315	265
	P	960	1030	1020	690	715
102	I	360	360	445	315	265
	P	965	1060	1000	715	740
103	I	360	360	440	315	270
	P	1030	1065	1030	735	760
104	I	365	375	450	320	280
	P	1040	1095	1040	735	750
105	I	365	370	450	320	280
	P	1040	1065	10[illegible]	700	760
106	I	360	365	450	320	275
	P	1015	1060	1010	705	800
107	I	365	360	445	320	270
	P	1015	1090	1000	685	735
108	I	365	365	440	315	275
	P	1020	1065	1030	660	705
109	I	370	375	445	325	275
	P	1030	1055	1050	690	705
110	I	370	380	445	325	280
	P	1035	1075	1035	715	805
111	I	380	380	450	330	285
	P	1020	1050	1025	705	770
112	I	380	380	450	330	285
	P	1020	1075	1040	705	760
113	I	380	380	445	325	280
	P	1035	1035	1030	710	770
114	I	375	370	450	325	290
	P	1020	1065	1030	670	705
115	I	365	375	445	325	280
	P	1020	1025	1035	690	720
116	I	380	375	440	325	280
	P	1000	1080	1040	710	795
117	I	380	375	445	335	265
	P	1020	1090	1015	705	755
118	I	385	385	450	330	285
	P	1010	1045	1020	690	725
119	I	385	385	460	335	300
	P	1000	1050	1010	665	670
120	I	390	385	460	330	290
	P	990	1045	1000	705	715
121	I	385	380	450	335	290
	P	1020	1045	975	660	705
122	I	385	390	440	330	275
	P	1030	1050	1030	710	750
123	I	390	385	440	335	285
	P	1015	1075	1000	740	750
124	I	390	390	440	345	295
	P	1040	1060	1010	710	755
125	I	390	390	445	340	295
	P	1035	1060	1000	730	730

TABLE III

INITIAL AND PEAK BORE SURFACE TEMPERATURES, LINED BARREL, AT EVERY 25 ROUNDS OF BURSTS NOS. 2 THROUGH 7

Round		Burst	Station 1	Station 2	Station 3	Station 5	Station 6
1	I	Burst No. 2	190	200	195	215	230
	P		975	975	850	640	675
25	I		390	395	485	370	375
	P		1060	1080	915	795	740
50	I		460	450	525	420	420
	P		1045	1095	930	735	790
75	I		485	460	515	430	385
	P		1050	1080	930	765	725
100	I		510	480	535	435	410
	P		1105	1035	960	730	735
125	I		525	585	540	450	405
	P		1075	1190	895	740	840
1	I	Burst No. 3	300	300	295	345	350
	P		1015	1075	770	685	750
25	I		510	600	520	485	445
	P		1125	1135	875	755	735
50	I		550	635	540	500	460
	P		1110	1220	880	770	845
75	I		530	625	505	470	430
	P		1080	1200	855	740	720
100	I		615	630	535	490	460
	P		1195	1240	945	745	710
125	I		645	655	575	520	490
	P		[illegible]	1220	935	870	790
1	I	Burst No. 4	320	370	375	435	435
	P		1075	1210	825	780	665
25	I		640	635	535	535	510
	P		1160	1335	1005	810	735
50	I		660	655	575	560	Failed
	P		1230	1380	955	835	
75	I		690	685	600	580	
	P		1200	1250	960	850	
100	I		650	655	575	550	
	P		1160	1105	925	795	
125	I		710	715	630	615	
	P		1230	1175	1030	885	

Round		Burst	Station 1	Station 2	Station 3	Station 5	Station 6
1	I	Burst No. 5	390	380	385	455	Failed
	P		1090	1080	915	805	
25	I		615	650	555	555	
	P		1140	-	1000	825	
50	I		640	580	590	575	
	P		1195	-	1120	935	
75	I		665	650	615	590	
	P		1145	-	1085	875	
100	I		650	700	620	600	
	P		1125	-	1135	945	
125	I		670	615	635	615	
	P		1115	-	1075	895	
1	I	Burst No. 6	410	410	420	500	
	P		1085	-	1025	890	
25	I		620	605	575	585	
	P		1015	-	985	875	
50	I		655	605	625	625	
	P		1135	-	1065	930	
75	I		680	665	640	645	
	P		1140	-	980	890	
100	I		695	680	670	665	
	P		1105	-	1065	960	
125	I		700	680	660	655	
	P		1150	-	975	915	
1	I	Burst No. 7	365	365	360	480	
	P		1010	-	915	770	
25	I		570	525	540	625	
	P		1150	-	930	875	
50	I		615	570	565	600	
	P		1090	-	880	860	
75	I		635	660	600	620	
	P		1065	-	905	860	
100	I		655	615	625	640	
	P		1130	-	885	870	
118	I		645	630	835	645	
	P		1090		950	915	

APPENDIX C

TABLE - EXTERNAL SURFACE TEMPERATURES OF UNLINED AND LINED BARRELS FOR STATIONS 4X AND 6X DURING FIRING TESTS

TABLE

EXTERNAL SURFACE TEMPERATURES OF UNLINED AND LINED BARRELS FOR STATIONS 4X AND 6X DURING FIRING TESTS

Unlined Barrel, 125-Round Bursts

Time-Event	Station 4X (°F)	Station 6X (°F)
0 Sec. - Start	77	77
13.7 - End	471	462
30 - Peak 4X	528	-
36 - Peak 6X	-	524
100 - Cooling	449	506
200 - Cooling	404	488
300 - Cooling	368	462
400 - Cooling	341	435
500 - Cooling	307	404
600 - Cooling	296	381
700 - Cooling	273	359

Lined Barrel, 125-Round Bursts

Time-Event	Station 4X (°F)	Station 6X (°F)
0 Sec. - Start, Burst 1	77	77
14 - End	282	355
26 - Peak, 6X	-	390
31 - Peak, 4X	359	-
78 - Start, Burst 2	318	377
92 - End	444	576
102- Peak, 6X	-	606
108 - Peak, 4X	515	-
153 - Start, Burst 3	475	576
164 - End	572	727
175 - Peak, 6X	-	756
183 - Peak, 4X	632	-
220 - Start, Burst 4	572	714
233.5 - End	572	790
244 - Peak, 6X	-	867
254 - Peak, 4X	697	-
277.5 - Start, Burst 5	675	824
291.5 - End	641	862
304 - Peak, 6X	-	943
309 - Peak, 4X	773	-

TABLE (Concluded)

Lined Barrel, 125-Round Bursts (Concluded

Time-Event	Station 4X (°F)	Station 6X (°F)
354.5 - Start, Burst 6	718	884
369 - End	718	909
384 - Peak, 6X	-	977
386 - Peak, 4X	807	-
416 - Start, Burst 7 Gun Jammed	-	-
525 - Start, Burst 7	593	820
539 - End	632	905
556 - Peak, 6X	-	939
556 - Peak, 4X	752	-
600 - Cooling	701	888
700 - Cooling	589	782
800 - Cooling	536	701
900 - Cooling	475	624
1000 - Cooling	444	563

APPENDIX D

Log of Tests of M60 Machine Gun Barrel

13 March 1971 - Ambient Temperature, 65°F

Test	Rounds	Notes
1	1	T/C 1, uninsulated Ch/Al, installed flush with bore. After firing, surface of T/C was coated with gray soot.
2	1	T/C 1, uninsulated Ch/Al, adjusted flush. After firing, surface of T/C was recessed 0.002 in. from bore surface, coated with gray soot.
3	5	T/C 1, uninsulated Ch/Al, initially 0.002 in. recessed. After firing, surface of sooty gray coating recessed 0.005 in., copper smear visible along edge of recess nearest chamber. Maximum temperature 1190°F, 5th round.
4	4	T/C 3, uninsulated Ch/Al, initially 0.002 in. recessed. After firing, surface of sooty gray coating recessed 0.005 in. Maximum temperature 1120°F, 4th round.
5	4	T/C A, insulated Ch/Al, installed flush. After firing, surface of sooty gray coating recessed 0.005 in. Maximum temperature 1410°F, 4th round.
6	5	T/C B, insulated Ch/Al, installed flush. After firing, surface of sooty gray coating recessed 0.005 in. Maximum temperature 1450°F, 1st round.

20 March 1971 - Ambient Temperature, 40°F

Test	Rounds	Notes
7	5	T/C B, insulated Ch/Al, installed flush. After firing, surface of sooty gray coating recessed 0.005 in., copper smear visible along edge of recess nearest chamber. Maximum temperature 1240°F, 1st round.
8	5	T/C B, insulated Ch/Al, adjusted flush. After firing, surface of sooty coating recessed 0.005 in., copper visible beneath gaps in soot. Maximum temperature 1000°F, 1st round.

9	10	T/C B, insulated Ch/Al, adjusted flush. After firing, surface of sooty coating recessed 0.002 in. Maximum temperature 750°F, 10th round.
10	10	T/C B, insulated Ch/Al, adjusted 0.002 in., protruding. After firing, surface of sooty coating flush with bore. Maximum temperature 1180°F, 8th round.
11	11	T/C A, insulated Ch/Al, installed flush. After firing, surface of sooty coating recessed 0.002in. Maximum temperature 1140°F, 6th round.
12	200	T/C A, insulated Ch/Al, Adjusted to 0.001 in. recessed. After firing, surface of sooty coating recessed 0.003 in., copper coating visible through gaps in soot. Maximum temperature 1330°F, 197th round.
		Temperatures noted after last round:

Seconds	Internal	External
10	490°	500°
26	450°	450°
46	400°	400°

		Attempted to install T/C C, insulated Ch/Al. Probe was so eccentric with respect to screw threads that it could not be properly seated.
13	10	T/C D, insulated Fe/Ni, installed flush with bore. After firing, surface of sooty coating recessed 0.001 in. Curled shaving of copper observed protruding from edge of recess. Maximum temperature indeterminate because of excessive noise in recording.
		Attempt to install T/C E, insulated Fe/Ni. Threaded shank broke before installation complete.
14	10	T/C F, insulated Fe/Ni, installed flush with bore. After firing, surface of sooty coating recessed 0.002 in. Curled shaving of copper observed protruding from edge of recess. Nickel center wire broken out on approximately 6th round.
		Maximum temperature 370°F, 2nd round, excessive noise in recording.

22 March 1971 - Laboratory Calibration of Bore Surface Thermocouples

Surface Temp., °F	T/C A, °F	T/C B, °F
500	491	493
1000	996	996
1100	1095	1096

Accuracy of temperature calibration estimated ± 4°F. Surface of thermocouples cleaned of copper coating after calibration.

31 March 1971 - Ambient Temperature, 70°F

15	10	T/C B, insulated Ch/Al, installed flush. After firing, surface of sooty coating recessed 0.005 in. Maximum temperature 1410°F, 1st round.
16	10	T/C B, insulated Ch/Al, adjusted flush. After firing, surface of sooty coating recessed 0.001 in. Maximum temperature 1340°F, 3rd round.
17	300	T/C B, insulated Ch/Al, initially recessed 0.001 in. After firing, bore not examined. Maximum temperature 1550°F, 101st round. Thermocouple extension wire broke on 243rd round.
18	280	T/C B, insulated Ch/Al, bore not examined before test. No temperature record available. Test started approximately 3 min. after preceding test. External surface temperature 715°F after 15 sec., 600°F after 30 sec., 550°F after 60 sec., and 500°F after 105 sec. Surface of sooty coating recessed 0.10 in. Soot was brushed away to reveal an irregular copper colored coating over the thermocouple. The screw body broke away from the probe when an attempt was made to remove the bore surface thermocouple. The probe is firmly swaged into the barrel.